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Headed Bars in Beam-Column Joints Subjected to Reversed Cyclic Loading

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Descriptive equations developed for the anchorage strength of headed bars in beam-column joints under monotonic load are evaluated for beam-column joints subjected to reversed cyclic loading. Test results from 23 studies that include 84 exterior and seven roof-level interior beam-column joints are used in the evaluation. Concrete compressive strengths and reinforcement yield strengths ranged from 3480 to 21,500 psi (24 to 148 MPa) and 53,700 to 150,000 psi (370 to 1030 MPa), respectively. Headed bar sizes ranged from slightly smaller than a No. 4 (No. 13) to No. 11 (No. 36) with net-bearing areas ranging from 1.7 to 8.6 times the bar area. The embedment lengths and center-to-center spacing between the headed bars ranged from eight to 18 bar diameters and from two to eight bar diameters, respectively. Analysis of the test data shows that descriptive equations based on headed bars under monotonic loading are also applicable to headed bars in beam-column joints subjected to reversed cyclic loading. These comparisons were used to justify the single approach used within the ACI Building Code for calculating the development length of headed bars.

Keywords: anchorage; beam-column joints; bond and development; development length; headed bars; high-strength concrete; high-strength reinforcement; reversed cyclic loading.

INTRODUCTION

The anchorage of hooked and headed reinforcing bars is achieved through combined bearing on the concrete (from a hook or head) and bond along the straight portion of the bar. The use of conventional hooked bars for anchorage in heavily reinforced members often causes congestion due to the extra length needed to accommodate the tail of the hook. Such congestion increases the difficulty of fabrication, construction, and concrete placement. Headed bars serve as a viable alternative to hooked bars and can also eliminate problems due to congestion. Section 25.4.4 of ACI 318-14[1] had provisions for the development of headed deformed bars in tension. That version of the code, however, limited the value of concrete compressive strength to 6000 psi (40 MPa) and steel yield strength to 60,000 psi (420 MPa) due to a lack of test data for higher strength materials. ACI 318-14 also limited the clear spacing between headed bars ($\geq 4d_b$) and clear concrete cover ($\geq 2d_b$), where d_b is the diameter of the bar and did not permit the use of confining reinforcement to reduce development length.

To address the limitations in ACI 318-14 for the anchorage of headed bars in concrete, a test program was undertaken to characterize the anchorage strength of headed bars that included 202 exterior beam-column joint specimens under monotonic loading.[2-4] The key parameters in those tests were concrete compressive strength (3960 to 16,000 psi [27 to 110 MPa]); embedment length (4 to 19.25 in. [102 to 489 mm]); bar size (No. 5, No. 8, and No. 11 [No. 16, No. 25, and No. 36]); head size (bearing areas from $3.8A_b$ to $15A_b$, where A_b is the area of the bar. All heads with bearing areas $\geq 4.0A_b$ met the requirements of ASTM A970-18[5]); number of headed bars loaded simultaneously in a specimen (2, 3, or 4); area of confining reinforcement within the joint region (ranging from none to $0.76A_b$); and center-to-center spacing between the bars ($2.9d_b$ to $11.8d_b$). The bar stresses at anchorage failure ranged from 26,000 to 153,000 psi (179 to 1050 MPa). Beam-column joint specimens with ratios of effective beam depth to embedment length d/ℓ_{eh} both below and above 1.5 were tested. Results for those with $d/\ell_{eh} > 1.5$ were not used to develop the descriptive equations described next.

The test data were used to support the development of descriptive equations for the anchorage strength of headed bars without and with confining reinforcement, shown in Eq. (1) and (2), respectively. The equations incorporate the effects of embedment length, concrete compressive strength, bar diameter, bar spacing, and confining reinforcement. The equations are applicable to a wide range of values for the key factors affecting the anchorage strength

$$T_h = \left(781 f_{cm}^{0.24} \ell_{eh}^{1.03} d_b^{0.35}\right)\left(0.0836\frac{c_{ch}}{d_b} + 0.344\right) \quad \text{(in.-lb) (1a)}$$

$$T_h = \left(132 f_{cm}^{0.24} \ell_{eh}^{1.03} d_b^{0.35}\right)\left(0.0836\frac{c_{ch}}{d_b} + 0.344\right) \quad \text{(SI) (1b)}$$

with $0.0836(c_{ch}/d_b) + 0.344 \leq 1.0$

$$T_h = \left(781 f_{cm}^{0.24} \ell_{eh}^{1.03} d_b^{0.35} + 48800\frac{A_{tt}}{n} d_b^{0.88}\right)\left(0.0622\frac{c_{ch}}{d_b} + 0.543\right) \quad \text{(in.-lb) (2a)}$$

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$$T_h = \left(132 f_{cm}^{\ 0.24} \ell_{eh}^{\ 1.03} d_b^{\ 0.35} + 19.5 \frac{A_{tt}}{n} d_b^{\ 0.88}\right) \quad \text{(SI) (2b)}$$

$$\left(0.0622 \frac{c_{ch}}{d_b} + 0.543\right)$$

with $0.0622\ (c_{ch}/d_b) + 0.543 \leq 1.0$ and $A_{tt}/n \leq 0.3A_b$.

where T_h is anchorage strength of an individual headed bar (lb or N); f_{cm} is measured concrete compressive strength (psi or MPa); ℓ_{eh} is embedment length (in. or mm), measured from the critical section (at the face of the supporting member) to the bearing face of the head; d_b is diameter of headed bar (in. or mm); c_{ch} is center-to-center spacing between headed bars (in. or mm); A_{tt} is total cross-sectional area of effective confining reinforcement within the joint and parallel to the headed bars being developed (in.^{2} or mm^2) equal to the product of the cross-sectional area of a single leg of confining reinforcement ($A_{tr,l}$) and the total number (N) of single legs of confining reinforcement parallel to the headed bars within $7.5d_b$ of the centerline of No. 3 through No. 8 (No. 10 through No. 25) headed bars or within $9.5d_b$ of the centerline of No. 9 through No. 11 (No. 29 through No. 36) headed bars; and n is the number of headed bars in tension. The term A_{tt}/n is the area of confining reinforcement per headed bar with an upper limit of $0.3A_b$.

In Eq. (1) and (2), a modification factor of 0.8 is applied to T_h for headed bars terminating inside a column core with clear cover to the bar (c_{so}) less than 2.5 in. (64 mm) or terminating in other members with c_{so} less than $8d_b$.

Equations (1) and (2) served as the basis for the new development length provisions for headed bars in ACI 318-19,[6] which among other things, permit a clear spacing between headed bars as low as $2d_b$ and the use of confining reinforcement to reduce development length. The goal of the work reported in this article is to evaluate the applicability of those equations (based on members subjected to monotonic loading) to members subjected to reversed cyclic loading. The test programs and development of the descriptive equations are presented by Shao et al.[3] and Ghimire et al.[2,4,7]

RESEARCH SIGNIFICANCE

Generalized equations to characterize the anchorage strength of headed bars are scarce in the literature, limiting the development of versatile design provisions for headed bars that account for a wide range of parameters, including concrete compressive strength, reinforcement yield strength, and member geometry and detailing. Based on recent research on headed bars, this paper establishes the applicability of descriptive equations developed for headed bars anchored in beam-column joints under monotonic loading to headed bars anchored in beam-column joints subjected to reversed cyclic loading. The work reported here supports the adoption of the single approach used in ACI 318-19 for calculating the development length of headed bars for both gravity and seismic loading.

HEADED BAR DATABASE FOR MEMBERS SUBJECTED TO REVERSED CYCLIC LOADING

A database of previous tests was assembled from 23 studies that included 84 exterior and seven roof-level interior beam-column joints subjected to reversed cyclic loading by Bashandy,[8] Murakami et al.,[9] Wallace et al.,[10] Matsushima et al.,[11] Nakazawa et al.,[12] Tasai et al.,[13] Yoshida et al.,[14] Takeuchi et al.,[15] Ishibashi et al.,[16] Ishibashi and Inokuchi,[17] Kiyohara et al.,[18,19] Kato,[20] Masuo et al.,[21] Adachi and Masuo,[22] Chun et al.,[23] Ishida et al.,[24] Tazaki et al.,[25] Lee and Yu,[26] Kang et al.,[27,28] Chun and Shin,[29] and Dhake et al.[30] In the exterior joint specimens, the beam reinforcement was anchored in the column using headed bars (Fig. 1(a)), and in the roof-level interior joint specimens, the column reinforcement was anchored in the beam using headed bars (Fig. 1(b)). As shown in Fig. 1(b), the headed bars in roof-level interior joint specimens were anchored outside of the beam reinforcement. The test parameters in these studies included the bearing area and embedment length of the headed bars, concrete compressive strength, bar spacing, bar size, and joint shear. Bar sizes ranged from a size slightly smaller than No. 4 (No. 13) through No. 11 (No. 36) with the net-bearing area of the heads (A_{brg}) ranging from $1.7A_b$ to $8.6A_b$. In this study, A_{brg} is calculated in accordance with the head dimension requirements of ASTM A970-18. Embedment lengths (ℓ_{eh}) ranged from $8d_b$ to $18d_b$. Concrete compressive strengths (f_{cm}) and longitudinal reinforcement yield strengths (f_y) ranged from 3480 to 21,500 psi (24 to 148 MPa) and from 53,700 to 150,000 psi (370 to 1030 MPa), respectively. The center-to-center spacing between the headed bars (c_{ch}) ranged from $2d_b$ to $8d_b$, whereas clear cover to the bar (c_{so}) within the joint region ranged from $1.5d_b$ to $9.9d_b$. All but four specimens (87 out of 91) contained transverse reinforcement within the joint region, with a center-to-center spacing (s_{tr}) ranging from $1.6d_b$ to $6.8d_b$. Seven exterior beam-column joint specimens contained transverse beams framing into the joint. The transverse beams, however, did not comply with the dimensional requirements in Sections 15.2.8 and 18.8.4.3 of ACI 318-19 and were not considered when calculating the joint strength. Column axial load applied during the test ranged from zero to $0.20A_g f_{cm}$, where A_g is the gross area of the column. Axial load was not applied to the columns representing roof-level interior joint specimens. The list of specimens and relevant test data are provided in Appendix A.* Results from these tests are analyzed using the descriptive equations, Eq. (1) and (2).

ANALYSIS OF TEST RESULTS

A detailed analysis of the test results from the 23 studies on headed bars in members subjected to reversed cyclic loading was conducted to investigate anchorage behavior.[7] For each specimen, the embedment length ℓ_{ehy} required to yield the headed bars was determined from the appropriate descriptive equation, Eq. (1) or (2), using $T_h = A_b f_y$ to solve for ℓ_{eh} with f_y based on the measured yield strength. The nominal

*The Appendix is available at **www.concrete.org/publications** in PDF format, appended to the online version of the published paper. It is also available in hard copy from ACI headquarters for a fee equal to the cost of reproduction plus handling at the time of the request.

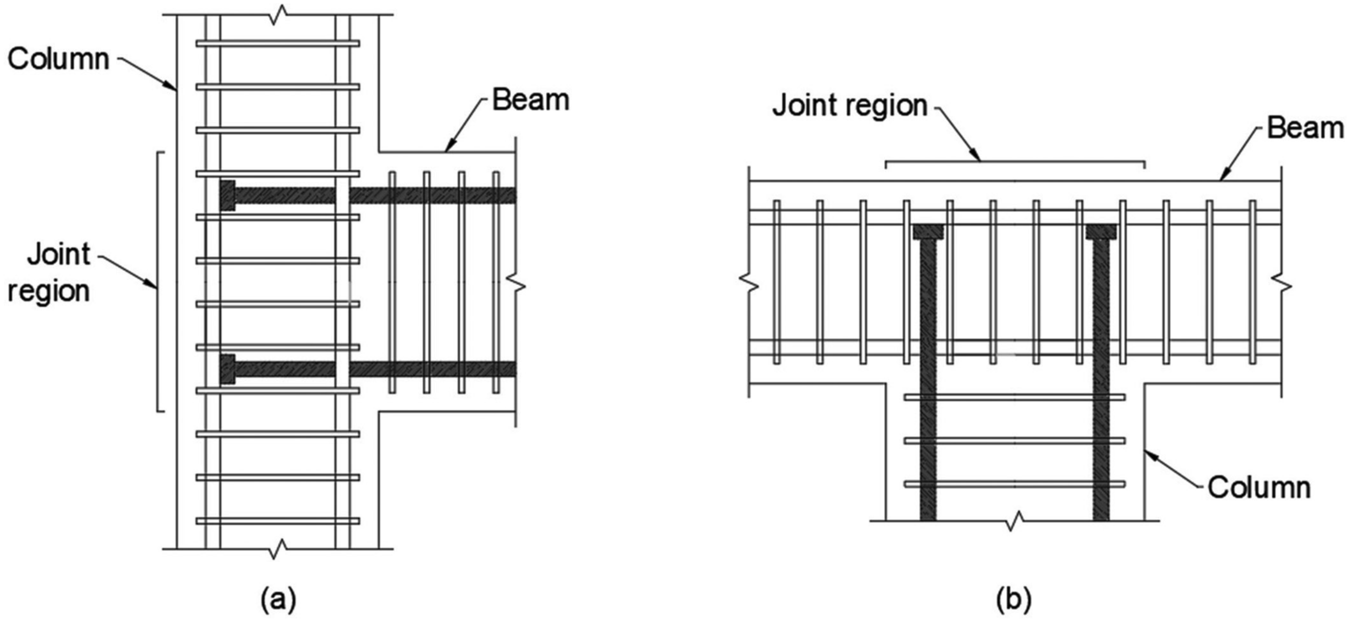

Fig. 1—(a) Exterior beam-column joint with beam reinforcement anchored in column using headed bars; and (b) roof-level interior beam-column joint with column reinforcement anchored in beam using headed bars.

flexural strength (M_n) of the test beam at an exterior joint (or column at a roof-level interior joint) was also calculated based on the measured yield strength f_y of the headed bars using the provisions of ACI 318-19. Compression reinforcement was neglected when calculating M_n unless the section was compression-controlled when ignoring such reinforcement, as was the case for specimens No. 102 to No. 104, M8D16, M4D19, M3D19, and M2D22 tested by Murakami et al.[9]; specimen No. 8 tested by Kiyohara et al.[19]; and specimens M0.7S and M0.7U tested by Chun and Shin.[29] These specimens were analyzed as doubly reinforced sections to obtain M_n. The peak moment (M_{peak}) applied during testing to the beam at an exterior joint (or column at a roof-level interior joint) was determined at the beam-column interface, which was taken as the critical section for the headed bars.

Beam-column joint specimens with a ratio of effective beam depth (d) at an exterior joint (or effective column depth at a roof-level interior joint) to embedment length $d/\ell_{eh} > 1.5$ were not used when developing Eq. (1) and (2). Therefore, only beam-column joint specimens with $d/\ell_{eh} \leq 1.5$ (ranging from 0.7 to 1.5), as recommended by ACI Code Commentary Section R25.4.4.2, were included in the evaluation. Of the 91 specimens in the database, 82 satisfied $d/\ell_{eh} \leq 1.5$.

The anchorage performance of the headed bars in beam-column joints subjected to reversed cyclic loading may be affected by high joint shear. Therefore, the ratio of peak joint shear (V_p) to nominal joint shear strength (V_n) was limited to $V_p/V_n \leq 1.3$ for specimens selected for further evaluation. The limit of 1.3 was selected to allow for cases where demand and capacity have a small deviation from their expected values. Of the 82 specimens, 74 satisfied the limit $V_p/V_n \leq 1.3$.

The peak joint shear V_p was calculated considering equilibrium at the joint using Eq. (3). The first term in the equation is the estimated total force in the headed bars in tension at the peak load, and the second term is the shear induced by M_{peak} in the supporting member with length L_c between the inflection points.

$$V_p = \left(\frac{M_{peak}}{M_n}\right) n A_b f_y - \frac{M_{peak}}{L_c} \tag{3}$$

If anchorage rather than flexural strength governed the total force in the headed bars, the first term of Eq. (3) would be replaced by nT_h, where T_h is based on Eq. (1) or (2). Figure 2 compares the tension forces in the individual headed bars based on $(M_{peak}/M_n)A_bf_y$ with those based on T_h. The figure shows that $(M_{peak}/M_n)A_bf_y$ is, in most cases, greater than T_h. The slope of the best-fit line shown in the figure is 1.09. Thus, the load in the bars at the peak moment, on average, exceeded the value of T_h obtained using Eq. (1) or (2), and the peak joint shear in the tests V_p, as represented by Eq. (3), was greater, on average, than a value corresponding to the anchorage strength of the bars.

The nominal joint shear strength V_n was calculated in accordance with the joint shear strength requirements of Section 18.8.4 of ACI 318-19 as $12\sqrt{f_c'}A_j$, using the measured compressive strength f_{cm} in place of f_c', but with an upper limit on f_c' of 10,000 psi (69 MPa). A_j is the effective cross-sectional area within the joint calculated based on Section 15.4.2.4 of ACI 318-19.

Figure 3 compares M_{peak}/M_n with ℓ_{eh}/ℓ_{ehy} for the 74 specimens with $V_p/V_n \leq 1.3$ and $d/\ell_{eh} \leq 1.5$. The figure includes trendlines for specimens with $\ell_{eh}/\ell_{ehy} < 1.0$ and $\ell_{eh}/\ell_{ehy} \geq 1.0$. The net-bearing areas of the headed bars in specimens included in the figure ranged from $1.7A_b$ to $8.6A_b$. An analysis of the 74 specimens included in Fig. 3 is presented next for cases where $\ell_{eh}/\ell_{ehy} < 1.0$ and $\ell_{eh}/\ell_{ehy} \geq 1.0$.

Specimens with $\ell_{eh}/\ell_{ehy} < 1.0$

The database contains 23 beam-column joint specimens with $\ell_{eh}/\ell_{ehy} < 1.0$, $V_p/V_n \leq 1.3$, and $d/\ell_{eh} \leq 1.5$. In Fig. 3, the trendline for the 23 specimens with $\ell_{eh}/\ell_{ehy} < 1.0$ shows an

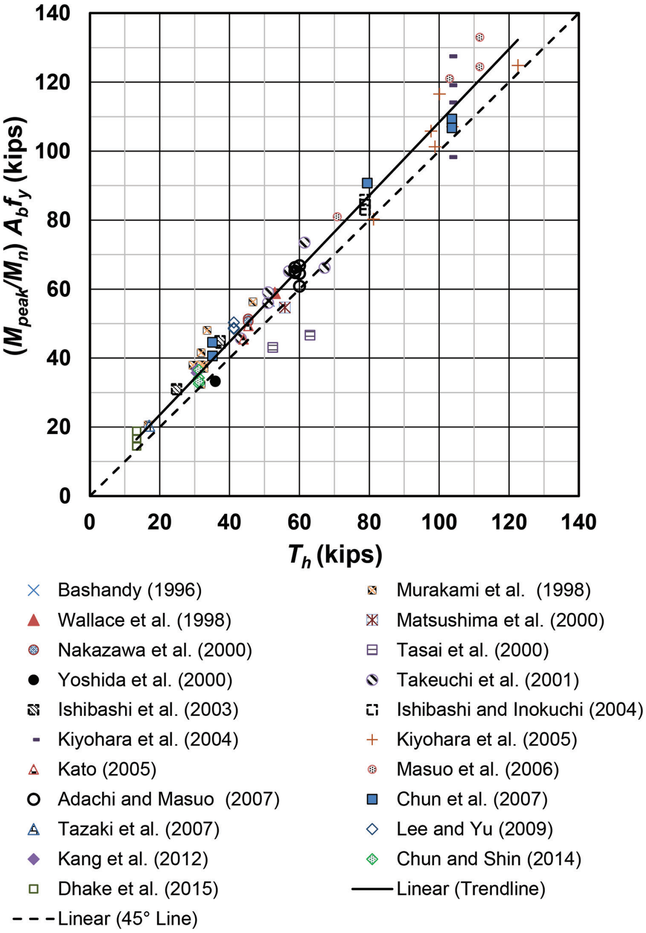

Fig. 2—Estimated bar force (M_{peak}/M_n)$A_b f_y$ *versus bar force* T_h *calculated using descriptive equation, Eq. (1) or (2), for specimens with* $d/\ell_{eh} \leq 1.5$ *and* $V_p/V_n \leq 1.3$.

increase in M_{peak}/M_n with an increase in ℓ_{eh}/ℓ_{ehy}, as expected. Of the 23 specimens, 15 had $\ell_{eh}/\ell_{ehy} \leq 0.88$ and $M_{peak}/M_n < 1.0$. The headed bars in 14 (of the 15) specimens with $\ell_{eh}/\ell_{ehy} \leq 0.88$ had yield strengths between 104,000 and 150,000 psi (717 and 1030 MPa) and the other specimen had a yield strength of 79,900 psi (551 MPa). These specimens exhibited significant joint deterioration, and none had flexural hinging within the beam (away from the joint region). The short embedment lengths of the headed bars, which were insufficient to yield the bars, played a role in the low strengths resulting in $M_{peak}/M_n < 1.0$. A total of eight specimens with ℓ_{eh}/ℓ_{ehy} ranging from 0.88 to 0.99[19,21,22] had $M_{peak}/M_n \geq 1.0$ for yield strengths of the headed bars ranging from 76,000 to 148,000 psi (524 to 1020 MPa). The fact that some specimens with $\ell_{eh}/\ell_{ehy} < 1.0$ reached $M_{peak}/M_n \geq 1.0$ was not unexpected because Eq. (1) and (2) represent the best fit of the monotonic test data with a mean test-to-calculated anchorage strength ratio of 1.00 and coefficients of variation of 0.10 and 0.11 for Eq. (1) and (2), respectively.

Specimens with $\ell_{eh}/\ell_{ehy} \geq 1.0$

For $\ell_{eh}/\ell_{ehy} \geq 1.0$, specimens are considered to have performed satisfactorily if: 1) the ratio of the peak moment to the nominal flexural strength $M_{peak}/M_n \geq 1.0$; and 2) the deformation capacity ($\delta_{0.8peak}$), or drift ratio attained before 20% loss of flexural strength was not less than 3%, where

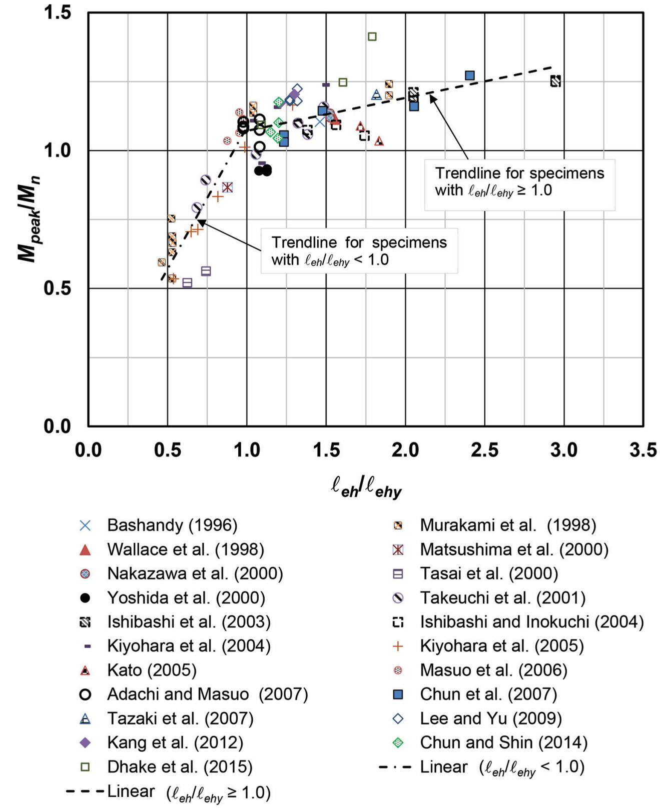

Fig. 3—M_{peak}/M_n *versus* ℓ_{eh}/ℓ_{ehy} *for specimens with* $d/\ell_{eh} \leq 1.5$ *and* $V_p/V_n \leq 1.3$.

the drift ratio is the angular rotation of the column chord with respect to the beam chord.

Specimens with embedment lengths sufficient to yield the headed bars ($\ell_{eh}/\ell_{ehy} \geq 1.0$) are expected to exhibit post-yield behavior characterized by a slight increase in strength due to strain hardening of the reinforcement. The test data for specimens with $\ell_{eh}/\ell_{ehy} \geq 1.0$ subjected to reversed cyclic loading are evaluated based on the descriptive equations to check if such post-yield behavior was realized.

In Fig. 3, 51 beam-column joint specimens have $\ell_{eh}/\ell_{ehy} \geq 1.0$. The trendline for these specimens shows $M_{peak}/M_n > 1$ and an increase with ℓ_{eh}/ℓ_{ehy}, but at a much lower rate of change than the trendline for specimens with $\ell_{eh}/\ell_{ehy} < 1.0$. This is consistent with yielding of the headed bars for $\ell_{eh}/\ell_{ehy} \geq 1.0$, with the increased strength likely due to strain hardening of the reinforcement. Out of the 51 specimens, 46 had $M_{peak}/M_n \geq 1.0$ and the other five had M_{peak}/M_n between 0.92 and 0.99. All 51 specimens with $\ell_{eh}/\ell_{ehy} \geq 1.0$ reached a drift ratio $\delta_{0.8peak} \geq 3\%$, as shown in Fig. 4. A drift ratio greater than or equal to 3% however, does not by itself indicate that a beam-column joint will perform adequately,[31-33] a point that is beyond the scope of this study.

The data shown in Fig. 3 and 4 indicate that providing an adequate development length for headed bars is needed to satisfy the performance requirements related to flexural strength and deformation capacity. The data further show that the length required to develop headed bars in beam-column joints subjected to reversed cyclic loading is well characterized by Eq. (1) and (2), which serve as the basis for the development length provisions for headed bars in

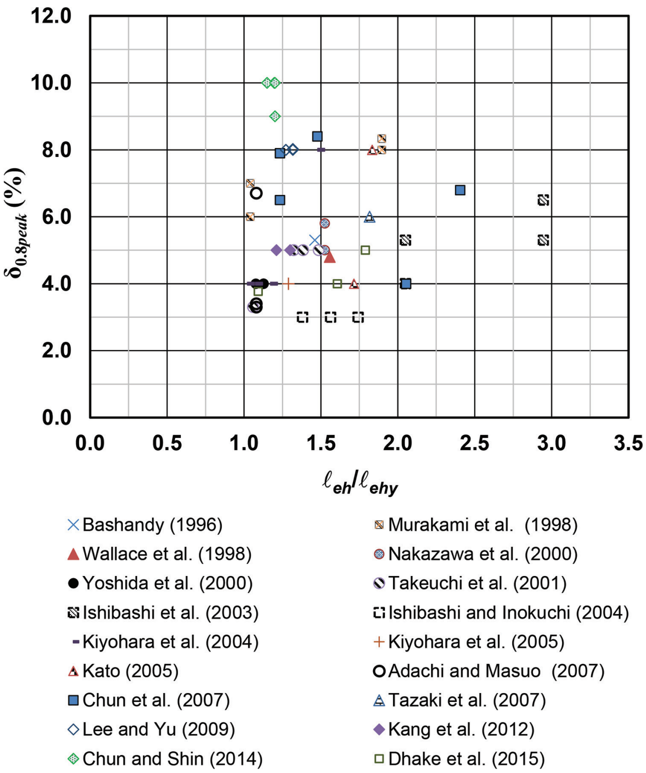

Fig. 4—Drift ratio, $\delta_{0.8peak}$ versus ℓ_{eh}/ℓ_{ehy} for specimens with $\ell_{eh}/\ell_{ehy} \geq 1.0$, $d/\ell_{eh} \leq 1.5$, and $V_p/V_n \leq 1.3$.

ACI 318-19. It is important to note that Section 18.8.5.2 of ACI 318-19 requires the use of 1.25 times the specified yield strength to determine the embedment length of headed bars (ℓ_{eh}) into beam-column joints of special moment frames. However, ℓ_{ehy} in Fig. 3 and 4 was determined based on the measured yield strength, which on average is approximately equal to 1.1 times the specified yield strength. Therefore, the requirement of using ℓ_{eh} based on 1.25 times the specified yield strength closely corresponds to $\ell_{eh}/\ell_{ehy} = 1.15$. The data in Fig. 3 and 4 show that all specimens with $\ell_{eh}/\ell_{ehy} \geq 1.15$ had $M_{peak}/M_n \geq 1.0$ and $\delta_{0.8peak} \geq 3\%$, supporting the requirements of Section 18.8.5.2 of ACI 318-19.

SUMMARY AND CONCLUSIONS

The applicability of the descriptive equations for the anchorage strength of headed bars in beam-column joints under monotonic load[3,4] to headed bars in beam-column joints subjected to reversed cyclic loading was evaluated. Test results from 23 studies that included 84 exterior and seven roof-level interior beam-column joints subjected to reversed cyclic loading were analyzed. Concrete compressive strengths and steel yield strengths ranged from 3480 to 21,500 psi (24 to 148 MPa) and from 53,700 to 150,000 psi (370 to 1030 MPa), respectively. Headed bar sizes ranged from slightly smaller than a No. 4 (No. 13) to No. 11 (No. 36) with net-bearing areas ranging from 1.7 to 8.6 times the bar area. The embedment lengths of the headed bars ranged from eight to 18 times the bar diameter (d_b). Clear cover and minimum center-to-center spacing between the bars ranged from $1.5d_b$ to $9.9d_b$ and from $2d_b$ to $8d_b$, respectively. In 87 out of 91 specimens (four without confining reinforcement), the headed bars were confined by hoops, spaced at $1.6d_b$ to $6.8d_b$ and parallel to the headed bar within the joint region. Column axial load applied during the test ranged from zero to $0.20A_gf_{cm}$. Of the 91 specimens in the database, 51 satisfied $d/\ell_{eh} \leq 1.5$, $V_p/V_n \leq 1.3$, and $\ell_{eh}/\ell_{ehy} \geq 1.0$. On average, these specimens satisfied minimum strength and deformation capacity with $M_{peak}/M_n \geq 1.0$ and $\delta_{0.8peak} \geq 3\%$.

Based on the analyses presented in this paper, it is concluded that the descriptive equations developed for beam-column joint specimens tested under monotonic loading are adequate for determining the required embedment length of headed bars in beam-column joints subjected to reversed cyclic loading and justify the single approach used within ACI 318-19 for calculating the development length of headed bars.

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NOTATION

A_b = cross-sectional area of individual headed bar
A_{brg} = net-bearing area of head of headed bar calculated in accordance with ASTM A970-18: as 1) gross head area minus maximum area of obstruction adjacent to head if obstruction has length and diameter not exceeding $5.25d_b$ and $2.2d_b$, respectively; 2) gross head area minus bar area if no obstruction is present or if obstruction has length measured from bearing face of head not more than $0.6d_b$ for No. 8 (No. 25) and larger bars or smaller of 0.6 in. and d_b for bars smaller than No. 8 (No. 25) and obstruction has a diameter not exceeding $1.5d_b$
A_g = gross cross-sectional area of column in exterior beam-column joint or beam in roof-level interior beam-column joint
A_j = effective cross-sectional area within beam-column joint in plane parallel to plane of headed bars
$A_{tr,l}$ = cross-sectional area of single leg of confining reinforcement parallel to headed bar within joint region
A_{tt} = total cross-sectional area of effective confining reinforcement ($NA_{tr,l}$) parallel to ℓ_{eh} for headed bars developed
c_{ch} = center-to-center spacing between adjacent headed bars

c_{so} = clear cover measured from headed bar to nearest concrete surface within anchorage region
d = distance from centroid of tension bar to extreme compression fiber of beam in exterior joints or column in roof-level interior joints
d_b = nominal diameter of headed bar
f_c' = specified concrete compressive strength
f_{cm} = measured compressive strength of concrete
f_y = measured yield strength of headed bar
L_c = length of supporting member (column in exterior joints and beam in roof-level interior joints) between inflection points
ℓ_{eh} = embedment length measured from critical section to bearing face of head
ℓ_{ehy} = embedment length required to yield headed bars calculated using descriptive equations (Eq. (1) and (2))
M_n = nominal flexural strength of beam in exterior joints or column in roof-level interior joints
M_{peak} = peak moment at critical section of headed bars in beam-column joints subjected to reversed cyclic loading
N = number of legs of effective confining reinforcement A_{tt} in joint region; number of legs of confining reinforcement parallel to headed bars within $8d_b$ from top of headed bars for No. 3 through No. 8 (No. 10 through No. 25) headed bars or within $10d_b$ from top of headed bars for No. 9 through No. 11 (No. 29 through No. 36)
n = number of headed bars loaded simultaneously in tension; number of headed bars confined by N legs; number of headed bars at tension face of beam in exterior joints or column in roof-level interior joints
s_{tr} = center-to-center spacing of transverse reinforcement within joint region
T_h = anchorage strength of headed bar calculated using descriptive equations (Eq. (1) or (2))
V_n = nominal joint shear strength calculated based on Section 18.8.4 of ACI 318-19
V_p = joint shear calculated using Eq. (3)
$\delta_{0.8peak}$ = drift ratio at drop to 80% from peak load (post peak)

REFERENCES

1. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)," American Concrete Institute, Farmington Hills, MI, 2014, 520 pp.

2. Ghimire, K. P.; Shao, Y.; Darwin, D.; and O'Reilly, M., "Conventional and High-Strength Headed Bars—Part 1: Anchorage Tests," *ACI Structural Journal*, V. 116, No. 3, May 2019, pp. 255-264. doi: 10.14359/51714479

3. Shao, Y.; Darwin, D.; O'Reilly, M.; Lequesne, R. D.; Ghimire, K. P.; and Hano, M., "Anchorage of Conventional and High-Strength Headed Reinforcing Bars," *SM Report* No. 117, The University of Kansas Center for Research, Lawrence, KS, Aug. 2016, 234 pp.

4. Ghimire, K. P.; Shao, Y.; Darwin, D.; and O'Reilly, M., "Conventional and High-Strength Headed Bars—Part 2: Data Analysis," *ACI Structural Journal*, V. 116, No. 3, May 2019, pp. 265-272. doi: 10.14359/51714480

5. ASTM A970/A970M-18, "Standard Specification for Headed Steel Bars for Concrete Reinforcement," ASTM International, West Conshohocken, PA, 2018, 10 pp.

6. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19)," American Concrete Institute, Farmington Hills, MI, 2019, 624 pp.

7. Ghimire, K. P.; Darwin, D.; and O'Reilly, M., "Anchorage of Headed Reinforcing Bars in Concrete," *SM Report* No. 127, The University of Kansas Center for Research, Lawrence, KS, Jan. 2018, 278 pp.

8. Bashandy, T. R., "Application of Headed Bars in Concrete Members," PhD dissertation, University of Texas at Austin, Austin, TX, Dec. 1996, 303 pp.

9. Murakami, M.; Fuji, T.; and Kubota, T., "Failure Behavior of Beam-Column Joints with Mechanical Anchorage in Subassemblage Frames," *Concrete Research and Technology*, V. 8, No. 1, 1998, pp. 1-9. doi: 10.3151/crt1990.9.1_1 (in Japanese)

10. Wallace, J. W.; McConnell, S. W.; Gupta, P.; and Cote, P. A., "Use of Headed Reinforcement in Beam-Column Joints Subjected to Earthquake Loads," *ACI Structural Journal*, V. 95, No. 5, Sept.-Oct. 1998, pp. 590-602.

11. Matsushima, M.; Kuramoto, H.; Maeda, M.; Shindo, K.; and Ozone, S., "Test on Corner Beam-Column Joint under Tri-Axial Loadings—Outline for Test: Study on Structural Performance of Mechanical Anchorage (No. 10); Discussion of Test Results: Study on Structural Performance of Mechanical Anchorage (No. 11) (in Japanese)," *Proceedings*, Architectural Institute of Japan, Tokyo, 2000, pp. 861-864.

12. Nakazawa, H.; Kumagai, H.; Saito, H.; Kurose, Y.; and Yabe, Y., "Development on the Ultra-High-Strength Reinforced Concrete Structure—Part 3: Loading Tests on Exterior Beam-Column Joints," *Proceedings*, Architectural Institute of Japan, Tokyo, Japan, 2000, pp. 611-612. (in Japanese)

13. Tasai, A.; Kawakatsu, K.; Kiyohara, T.; and Murakami, M., "Shear Performance of Exterior Beam Column Joint with Beam Main Bars Anchored Mechanically—Part 1: Study on Structural Performance of Mechanical Anchorage (No. 8)," *Proceedings*, Architectural Institute of Japan, Tokyo, Japan, 2000, pp. 857-864. (in Japanese)

14. Yoshida, J.; Ishibashi, K.; and Nakamura, K., "Experimental Study on Mechanical Anchorage Using Bolt and Nut in Exterior Beam-Column Joint—Part 1: Specimens and Outline of Experiment and Part 2: Analysis of Experiment," *Proceedings*, Architectural Institute of Japan, Tokyo, Japan, 2000, pp. 635-638. (in Japanese)

15. Takeuchi, H.; Kishimoto, T.; Hattori, S.; Nakamura, K.; Hosoya, H.; and Ichikawa, M., "Development of Mechanical Anchorage Used Circular Anchor Plate—Part 3: Outline of Exterior Beam-Column Joint Test and Experimental Results and Part 4: Experimental Results and Discussion of Exterior Beam-Column Joint Test," *Proceedings*, Architectural Institute of Japan, Tokyo, Japan, 2001, pp. 111-114. (in Japanese)

16. Ishibashi, K.; Inokuchi, R.; Ono, H.; and Masuo, K., "Experimental Study on T-Shaped Beam-Column Joints with Anchor-Heads on Column's Rebars—Part 1: Ductilities and Strength and Part 2: Deformations," *Proceedings*, Architectural Institute of Japan, Tokyo, 2003, pp. 533-536. (in Japanese)

17. Ishibashi, K., and Inokuchi, R., "Experimental Study on T-Shaped Joints with Anchor-Heads on Column's Rebars—Part 3: Loading Capacity and Ductility of Full-Scale Specimens," *Proceeding*, Architectural Institute of Japan, Tokyo, Japan, Aug. 2004, pp. 819-820. (in Japanese)

18. Kiyohara, T.; Tasai, A.; Watanabe, K.; Hasegawa, Y.; and Fujimoto, T., "Seismic Capacity of High Strength RC Exterior Beam Column Joint with Beam Main Bars Anchored Mechanically—Part 1: Anchorage Performance and Estimation of Strength; Part 2: Restoring Force Characteristics and Displacement Component; Part 3; Failure Modes and Width of Crack; and Part 4: Anchorage Performance and Estimation of Strength," *Proceedings*, Architectural Institute of Japan, Tokyo, Japan, 2004, pp. 27-34. (in Japanese)

19. Kiyohara, T.; Hasegawa, Y.; Fujimoto, T.; Akane, J.; Amemiya, M.; Tasai, A.; and Adachi, T., "Seismic Performance of High Strength RC Exterior Beam Column Joint with Beam Main Bars Anchored Mechanically—Part 5: Anchorage Performance and Estimation for Strength; Part 6: Experimental Result on Shear Failure Models; Part 7: Anchorage Performance and Estimation for Strength (Specimens No. 6-10); Part 8: Experimental Study and Estimation for Strength (Specimens No. 11-12); and Part 9: Behavior of Crack," *Proceedings*, Architectural Institute of Japan, Tokyo, Japan, 2005, pp. 35-42. (in Japanese)

20. Kato, T., "Mechanical Anchorage Using Anchor Plate for Beam/Column Joints of R/C Frames—Part 2: Pull-Out Behavior and Structural Behavior of T-Shaped Frame Using Frictional Anchor Plate," *Proceedings*, Architectural Institute of Japan, Tokyo, Japan, 2005, pp. 277-278. (in Japanese)

21. Masuo, K.; Adachi, M.; and Imanishi, T., "Ultimate Strength of R/C Exterior Beam-Column Joint Using Mechanical Anchorage for Beam Reinforcement USD590—Part 1: Experiment on Anchorage Strength of Beam Reinforcement and Part 2: Experiment on Shear Strength of Beam-Column Joint," *Proceedings*, Architectural Institute of Japan, Tokyo, 2006, pp. 25-28. (in Japanese)

22. Adachi, M., and Masuo, K., "The Effect of Orthogonal Beams on Ultimate Strength of R/C Exterior Beam-Column Joint Using Mechanical Anchorages," *Proceedings*, Architectural Institute of Japan, Tokyo, Japan, 2007, pp. 633-634. (in Japanese)

23. Chun, S. C.; Lee, S. H.; Kang, T. H.; Oh, B.; and Wallace, J. W., "Mechanical Anchorage in Exterior Beam-Column Joints Subjected to Cyclic Loading," *ACI Structural Journal*, V. 104, No. 1, Jan.-Feb. 2007, pp. 102-112.

24. Ishida, Y.; Fujiwara, A.; Adachi, T.; Matsui, T.; and Kuramoto, H., "Structural Performance of Exterior Beam-Column Joint with Wide Width Beam Using Headed Bars—Part 1: Outline of Test and Failure Modes and Part 2: Test Results and Discussion," *Proceedings*, Architectural Institute of Japan, Tokyo, Japan, 2007, pp. 657-660. (in Japanese)

25. Tazaki, W.; Kusuhara, F.; and Shiohara, H., "Tests of RC Beam-Column Joints with Irregular Details on Anchorage of Beam Longitudinal Bars—Part 1: Outline of Tests and Part 2: Test Results and Discussions," *Proceedings*, Architectural Institute of Japan, Tokyo, Japan, 2007, pp. 653-656. (in Japanese)

26. Lee, H.-J., and Yu, S.-Y., "Cyclic Response of Exterior Beam-Column Joints with Different Anchorage Methods," *ACI Structural Journal*, V. 106, No. 3, May-June 2009, pp. 329-339.

27. Kang, T. H.; Ha, S.-S.; and Choi, D.-U., "Bar Pullout Tests and Seismic Tests of Small-Headed Bars in Beam-Column Joints," *ACI Structural Journal*, V. 107, No. 1, Jan.-Feb. 2010, pp. 32-42.

28. Kang, T. H.; Kim, W.; and Shin, M., "Cyclic Testing for Seismic Design Guide of Beam-Column Joints with Closely Spaced Headed Bars,"

Journal of Earthquake Engineering, V. 16, No. 2, 2012, pp. 211-230. doi: 10.1080/13632469.2011.610497

29. Chun, S. C., and Shin, Y.-S., "Cyclic Testing of Exterior Beam-Column Joints with Varying Joint Aspect Ratio," *ACI Structural Journal*, V. 111, No. 3, May-June 2014, pp. 693-704. doi: 10.14359/51686730

30. Dhake, P. D.; Patil, H. S.; and Patil, Y. D., "Anchorage Behaviour and Development Length of Headed Bars in Exterior Beam-Column Joints," *Magazine of Concrete Research*, V. 67, No. 2, 2015, pp. 53-62. doi: 10.1680/macr.14.00144

31. ACI Committee 352, "Recommendations for Design of Beam-Column Connections in Monolithic Reinforced Concrete Structures (ACI 352R-02) (Reapproved 2010)," American Concrete Institute, Farmington Hills, MI, 2002, 38 pp.

32. ACI Committee 369, "Standard Requirements for Seismic Evaluation and Retrofit of Existing Concrete Buildings (ACI 369.1-17) and Commentary," American Concrete Institute, Farmington Hills, MI, 2017, 110 pp.

33. ACI Committee 374, "Acceptance Criteria for Moment Frames Based on Structural Testing and Commentary (ACI 374.1-05, Reapproved 2019)," American Concrete Institute, Farmington Hills, MI, 2005, 9 pp.

34. ASTM A970/A970M-13a, "Standard Specification for Headed Steel Bars for Concrete Reinforcement," ASTM International, West Conshohocken, PA, 2013, 9 pp.

35. Choi, D.-U., "Test of Headed Reinforcement in Pullout II: Deep Embedment," *International Journal of Concrete Structures and Materials*, V. 18, No. 3, Aug. 2006, pp. 151-159.

36. Choi, D.-U.; Hong, S.-G.; and Lee, C.-Y., "Test of Headed Reinforcement in Pullout," *KCI Concrete Journal*, V. 14, No. 3, Sep. 2002, pp. 102-110.

37. Kang, T. H.; Shin, M.; Mitra, N.; and Bonacci, J. F., "Seismic Design of Reinforced Concrete Beam-Column Joints with Headed Bars," *ACI Structural Journal*, V. 106, No. 6, Nov.-Dec. 2009, pp. 868-877.

38. Thompson, M. K.; Ledesma, A.; Jirsa, J. O.; and Breen, J. E., "Lap Splices Anchored by Headed Bars," *ACI Structural Journal*, V. 103, No. 2, Mar.-Apr. 2006, pp. 271-279.

APPENDIX A: NOTATION AND DATA TABLES

A.1 NOTATION

A_b Cross-sectional area of an individual headed bar

A_{brg} Net bearing area of the head of headed bar calculated in accordance with ASTM A970-18 as (1) gross head area minus maximum area of the obstruction adjacent to the head if the obstruction has length and diameter not exceeding $5.25d_b$ and $2.2d_b$, respectively; (2) gross head area minus bar area if no obstruction is present or if the obstruction has length measured from the bearing face of the head not more than $0.6d_b$ for No. 8 (No. 25) and larger bars or the smaller of 0.6 in. and d_b for bars smaller than No. 8 (No. 25) and the obstruction has a diameter not exceeding $1.5d_b$

A_g Gross cross-sectional area of column in exterior beam-column joint or beam in roof-level interior beam-column joint

A_{gross} Gross cross-sectional area of the head

A_{hs} Total cross-sectional area of headed bars being developed (nA_b)

A_j Effective cross-sectional area within the beam-column joint in a plane parallel to the plane of headed bars

A_{Nc} Projected concrete failure area of a single headed bar or group of headed bars as per Chapter 17 of ACI 318-19

A_{obs} Gross cross-sectional area of the obstruction adjacent to the bearing face of the head

A_{tr} Cross-sectional area of confining reinforcement crossing the potential plane of splitting

$A_{tr,l}$ Cross-sectional area of a single leg of confining reinforcement parallel to the headed bar within the joint region

$A_{tro,l}$ Cross-sectional area of a single leg of confining reinforcement parallel to the headed bar outside the joint region

A_{tt} Total cross-sectional area of effective confining reinforcement ($NA_{tr,l}$) parallel to ℓ_{eh} for headed bars being developed

A_v Total cross-sectional area of confining reinforcement parallel to the headed bar (N_{total} $A_{tr,l}$) assumed to serve as a single tie

b_b Width of beam in exterior beam-column joints or width of column in roof-level interior beam-column joints

b_c Width of column in exterior beam-column joints or width of beam in roof-level interior beam-column joints

b_j Effective width of beam-column joint perpendicular to the headed bars in tension calculated based on Section 15.4.2.4 of ACI 318-19

$b_{j,ACI352}$ Effective width of beam-column joint perpendicular to the headed bars in tension calculated based on Section 4.3.1 of ACI 352R-02

c_{ch} Center-to-center spacing between adjacent headed bars

c_o Clear cover measured from the head to the nearest concrete surface

c_{so} Clear cover measured from the headed bar to the nearest concrete surface within the anchorage region

d Distance from the centroid of the tension bar to the extreme compression fiber of the beam in exterior joints or column in roof-level interior joints

d' Distance from the centroid of the compression bar to the extreme compression fiber of the beam in exterior joints or column in roof-level interior joints

d_b Nominal diameter of the headed bar

$d_{b,sprt}$ Nominal diameter of reinforcement in the supporting member - column in exterior joint and beam in roof-level interior joint

f_{cm} Measured compressive strength of concrete

f_c' Specified concrete compressive strength

f_y Measured yield strength of the headed bar

$f_{y,sprt}$ Measured yield strength of reinforcing bars in the supporting member - column in exterior joint and beam in roof-level interior joint

f_{yt} Measured yield strength of confining reinforcement parallel to the headed bar within the join region

f_{yto} Measured yield strength of confining reinforcement parallel to the headed bar outside the joint region

h_b Depth of beam in exterior beam-column joints or depth of column in roof-level interior beam-column joints

h_c Depth of column in exterior beam-column joints or depth of beam in roof-level interior beam-column joints

L_c Length of column in exterior beam-column joints or length of beam in roof-level interior beam-column joints between inflection points

ℓ_{dt} Development length in tension of headed bar, measured from the critical section to the bearing face of the head based on Eq. (5.2) in Ghimire et al. (2018)

ℓ_{dy} Development length in tension of straight deformed bar (headed bar treated as straight bar by ignoring the head) calculated in accordance with Eq. (4-11a) of ACI 408R-03 using □□= 1.0

ℓ_{eh} Embedment length measured from the critical section to the bearing face of the head

ℓ_{ehy} Embedment length required to yield the headed bars calculated using the descriptive equations, Eq. (1) and (2)

M_{peak} Peak moment at critical section of headed bars in beam-column joints subjected to reversed cyclic loading

M_n Nominal flexural strength of beam in exterior joints or column in roof-level interior joints

n Number of headed bars loaded simultaneously in tension; number of headed bars confined by N legs; number of headed bars at the tension face of the beam in exterior joints or the column in roof-level interior joints

$n_{l,sprt}$ Number of longitudinal bars around the perimeter of the supporting member that are laterally supported by the corner of hoops or cross-ties within the join region

n_{sprt} Total number of longitudinal bars within the joint region of the supporting member

N Number of legs of effective confining reinforcement A_{tt} in the joint region; number of legs of confining reinforcement parallel to headed bars within $8d_b$ from top of headed bars for No. 3 through No. 8 (No. 10 through No. 25) headed bars or within $10d_b$ from top of headed bars for No. 9 through No. 11 (No. 29 through No. 36)

N_{arg} Nominal anchorage strength of a group of headed bars based on steel strength of anchor reinforcement

N_{cbg} Nominal concrete breakout strength of a group of headed bars in tension

N_{sb} Nominal side-face blowout strength of a single headed bar in tension

N_{sbg} Nominal side-face blowout strength of a group of headed bars in tension

N_{splt} Total number of column (or beam) longitudinal bars, considered as confining reinforcement, crossing the potential plane of splitting, used as N when calculating ℓ_{dy}

N_{total} Total number of legs of confining reinforcement within a beam-column joint

N_{tr} Total number of legs of anchor reinforcement parallel to the headed bars within $0.5\ell_{eh}$ radial distance from the center of the bar in column-like specimens; total number of legs of anchor reinforcement parallel to the headed bars within $0.5\ell_{eh}$ from the center of the headed bar in the direction of the interior of beam-column joint

N_{tro} Total number of legs of anchor reinforcement parallel to the headed bars within $0.5\ell_{eh}$ from the center of the headed bar in the direction outside of the beam-column joint

P Column axial load applied during the test of beam-column joints

s_h Center-to-center spacing between headed bars in a layer

s_{tr} Center-to-center spacing of confining reinforcement within the joint region

s'_{tr} Center-to-center spacing between the first confining reinforcement within the joint region and the nearest headed bar in tension

s_{tro} Center-to-center spacing of confining reinforcement outside joint region

s'_{tro} Center-to-center spacing between the first confining reinforcement outside the joint region and the nearest headed bar in tension

s_v Center-to-center spacing between headed bars in adjacent layers

T' Estimated strength of a headed bar in beam-column joints subjected to reversed cyclic loading calculated using Eq. (4.4) in Ghimire et al. (2018)

T'_{mod} Modified bar force T' in beam-column joint specimens with $\ell_{eh} \geq \ell_{ehy}$ calculated using Eq. (4.5) in Ghimire et al. (2018)

T_{anc} Nominal anchorage strength of each headed bar in tension in beam-column joints governed by concrete breakout, concrete side-face blowout, or steel strength of anchor reinforcement, calculated based on anchorage design provisions in Chapter 17 of ACI 318-19

T_h Anchorage strength of a headed bar calculated using descriptive equations, Eq. (1) or (2)

t_{obs} Length of the obstruction measured from the bearing face of the head

V_n Nominal joint shear strength calculated based on Section 18.8.4 of ACI 318-19

$V_{n,ACI352}$ Nominal joint shear strength calculated based on Section 4.3 of ACI 352R-02

V_p Peak joint shear applied at the beam-column joint

$\delta_{0.8peak}$ Drift ratio at drop to 80% from the peak load (post peak)

δ_y Drift ratio at first yield of longitudinal reinforcement

Υ_j Angular distortion (due to shear) of a beam-column joint associated with a deformation of approximately 3.5% drift

$□_{cs}$ Factor used to modify development length based on confining reinforcement and bar spacing in accordance with Chapter 5 of Ghimire et al. (2018)

$□_o$ Factor used to modify development length of headed bar based on side cover and confinement

A.2 TEST RESULTS AND DETAILS OF SPECIMENS

Table A.1 Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

	Study	Specimen	Bar Size **	A_b (in.²)	A_{brg}/A_b	A_{gross}/A_b	A_{hs} (in.²)	A_{Nc} (in.²)	A_{obs}/A_b	A_{tr} (in.²)	$A_{tr,l}$ (in.²)	$A_{tro,l}$ (in.²)	A_{tt} (in.²)	A_{tt}/A_{hs}
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Bashandy (1996)	Exterior Joint	D25	0.79	8.6	9.6	1.58	412	-	0.60	0.20	0.20	1.20	0.76
2	Murakami et al. (1998)	No. 100	D16	0.31	1.7	2.7	1.24	314	-	0.44	0.05	0.05	0.20	0.16
		No. 101	D16	0.31	6.3	7.3	1.24	314	-	0.44	0.05	0.05	0.20	0.16
		B8-M	D19	0.44	6.0	7.0	1.32	314	-	0.44	0.05	0.05	0.20	0.15
		B7-M	D19	0.44	6.0	7.0	1.32	314	-	0.44	0.05	0.05	0.20	0.15
		No. 102 ‡	D19	0.44	2.1	3.1	1.76	314	-	0.44	0.05	0.05	0.20	0.11
		No. 103 ‡	D19	0.44	5.8	6.8	1.76	314	-	0.44	0.05	0.05	0.20	0.11
		No. 104 ‡	D19	0.44	3.4	4.4	1.76	314	-	0.44	0.05	0.05	0.20	0.11
		M8D16 ‡	D16	0.31	4.4	7.0	2.48	337	2.6	0.44	0.05	0.05	0.10	0.04
		M4D19 ‡	D19	0.44	3.9	7.0	1.76	314	3.1	0.44	0.05	0.05	0.20	0.11
		M3D19 ‡	D19	0.44	3.9	7.0	1.32	314	3.1	0.44	0.05	0.05	0.20	0.15
		M2D22 ‡	D22	0.60	3.6	7.0	1.20	314	3.4	0.44	0.05	0.05	0.29	0.25
3	Wallace et al. (1998)	BCEJ1 ‡‡	No. 8	0.79	4.0	5.0	3.16	751	-	1.00	0.20	0.20	1.20	0.38
4	Matsushima et al. (2000)	H	D25	0.79	-	-	2.37	549	-	0.60	0.11	0.11	0.44	0.19
		HS §	D25	0.79	-	-	2.37	372	-	0.60	0.11	0.11	0.44	0.19
5	Nakazawa et al. (2000)	J1	D19	0.44	3.9	6.9	2.64	515	3.0	0.44	0.05	0.05	0.37	0.14
		J2	D19	0.44	5.9	6.9	2.64	515	-	0.44	0.05	0.05	0.37	0.14
6	Tasai et al. (2000)	No. 6	D25	0.79	5.4	9.0	3.16	558	3.6	1.58	0.11	0.11	0.44	0.14
		No. 7	D25	0.79	5.4	9.0	1.58	558	3.6	1.58	0.11	0.11	0.44	0.28
7	Yoshida et al. (2000)	No. 1	D19	0.44	5.8	6.8	1.76	361	-	0.44	0.11	0.11	0.44	0.25
		No. 2	D19	0.44	4.1	5.1	1.76	361	-	0.44	0.11	0.11	0.44	0.25
		No. 3	D19	0.44	3.1	4.1	1.76	361	-	0.44	0.11	0.11	0.44	0.25
8	Takeuchi et al. (2001)	0-1	D25	0.79	5.8	6.8	2.37	491	-	0.60	0.11	0.11	0.44	0.19
		0-2	D25	0.79	5.8	6.8	2.37	491	-	0.60	0.11	0.11	0.44	0.19
		0-3	D25	0.79	5.8	6.8	2.37	491	-	0.60	0.11	0.11	0.44	0.19
		0-4	D25	0.79	5.8	6.8	2.37	551	-	0.60	0.11	0.11	0.44	0.19
		0-6	D25	0.79	5.8	6.8	3.16	491	-	0.60	0.11	0.11	0.44	0.14
		0-7	D25	0.79	5.8	6.8	3.16	491	-	0.60	0.11	0.11	0.44	0.14
9	Ishibashi et al. (2003) §§	T345-30-4S	D19	0.44	3.2	6.4	1.32	545	3.2	0.75	0.11	0.11	0.44	0.34
		T345-30-3N	D19	0.44	3.2	6.4	1.32	545	3.2	0.75	0.11	0.11	0.44	0.34
		T490-45-4S	D19	0.44	3.2	6.4	1.32	545	3.2	0.75	0.11	0.11	0.44	0.34
		T490-45-3N	D19	0.44	3.2	6.4	1.32	545	3.2	0.75	0.11	0.11	0.44	0.34

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

** Bar sizes are presented in SI as reported in the original studies (only Wallace et al. 1998 had bar sizes reported in in.-lb)

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimen had $d/\ell_{eh} > 1.5$

§§ Roof-level interior joints; all other specimens are exterior joints

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	A_v (in.^{2})	b_b (in.)	b_c (in.)	b_j (in.)	$b_{j,ACI352}$ (in.)	c_{ch} (in.)	c_{ch}/d_b	c_o (in.)	c_o/d_b	c_{so} (in.)	c_{so}/d_b	d (in.)	d/ℓ_{eh}
	1	2	15	16	17	18	19	20	21	22	23	24	25	26	27
1	Bashandy (1996)	Exterior Joint	2.00	10.0	12	12.0	11.0	5.0	5.1	2.4	2.5	3.5	3.6	15.5	1.4
2	Murakami et al. (1998)	No. 100	0.39	10.2	12	11.8	11.0	2.2	3.5	2.1	3.4	2.3	3.8	13.6	1.5
		No. 101	0.39	10.2	12	11.8	11.0	2.2	3.5	1.8	2.9	2.3	3.8	13.6	1.5
		B8-M	0.39	10.2	12	11.8	11.0	3.2	4.3	1.7	2.2	2.3	3.0	13.6	1.5
		B7-M	0.39	10.2	12	11.8	11.0	3.2	4.3	1.7	2.2	2.3	3.0	13.6	1.5
		No. 102 ‡	0.39	10.2	12	11.8	11.0	2.2	2.9	2.0	2.7	2.3	3.0	13.6	1.5
		No. 103 ‡	0.39	10.2	12	11.8	11.0	2.2	2.9	1.7	2.2	2.3	3.0	13.6	1.5
		No. 104 ‡	0.39	10.2	12	11.8	11.0	2.2	2.9	1.9	2.5	2.3	3.0	13.6	1.5
		M8D16 ‡	0.39	10.2	12	11.8	11.0	2.0	3.2	1.8	2.9	2.3	3.8	13.0	1.5
		M4D19 ‡	0.39	10.2	12	11.8	11.0	2.2	2.9	1.7	2.2	2.3	3.0	13.6	1.5
		M3D19 ‡	0.39	10.2	12	11.8	11.0	3.2	4.3	1.7	2.2	2.3	3.0	13.6	1.5
		M2D22 ‡	0.39	10.2	12	11.8	11.0	6.5	7.4	1.5	1.7	2.2	2.5	13.6	1.5
3	Wallace et al. (1998)	BCEJ1 ‡‡	2.40	18.0	18	18.0	18.0	3.5	3.5	-	-	-	-	21.5	1.5
4	Matsushima et al. (2000)	H	0.66	13.8	16	15.7	14.8	5.0	5.1	-	-	2.3	2.3	15.1	1.3
		HS §	0.66	13.8	16	15.7	14.8	5.0	5.1	-	-	2.3	2.3	15.1	1.9
5	Nakazawa et al. (2000)	J1	0.56	11.0	14	14.2	12.6	2.6	3.4	2.1	2.8	2.7	3.6	11.8	1.1
		J2	0.56	11.0	14	14.2	12.6	2.6	3.4	2.1	2.8	2.7	3.6	11.8	1.1
6	Tasai et al. (2000)	No. 6	0.66	13.8	16	15.7	14.8	3.1	3.1	1.4	1.4	2.4	2.4	15.2	1.3
		No. 7	0.66	13.8	16	15.7	14.8	4.7	4.7	1.4	1.4	2.4	2.4	15.2	1.3
7	Yoshida et al. (2000)	No. 1	1.11	11.8	12	11.8	11.8	2.8	3.7	1.8	2.4	2.4	3.2	14.0	1.4
		No. 2	1.11	11.8	12	11.8	11.8	2.8	3.7	1.9	2.5	2.4	3.2	14.0	1.4
		No. 3	1.11	11.8	12	11.8	11.8	2.8	3.7	2.0	2.7	2.4	3.2	14.0	1.4
8	Takeuchi et al. (2001)	0-1	0.66	13.8	16	15.7	14.8	4.8	4.9	1.7	1.7	2.5	2.6	15.6	1.5
		0-2	0.66	13.8	16	15.7	14.8	4.8	4.9	1.7	1.7	2.5	2.6	15.6	1.5
		0-3	0.66	13.8	16	15.7	14.8	4.8	4.9	1.7	1.7	2.5	2.6	15.6	1.5
		0-4	0.66	13.8	16	15.7	14.8	4.8	4.9	1.7	1.7	2.5	2.6	15.6	1.3
		0-6	0.66	13.8	16	15.7	14.8	3.2	3.3	1.7	1.7	2.5	2.6	15.6	1.5
		0-7	0.66	13.8	16	15.7	14.8	3.2	3.3	1.7	1.7	2.5	2.6	15.6	1.5
9	Ishibashi et al. (2003) §§	T345-30-4S	0.66	15.7	12	11.8	11.8	5.6	7.5	1.3	1.7	1.9	2.5	13.5	1.0
		T345-30-3N	0.66	15.7	12	11.8	11.8	5.6	7.5	1.3	1.7	1.9	2.5	13.5	1.0
		T490-45-4S	0.66	15.7	12	11.8	11.8	5.6	7.5	1.3	1.7	1.9	2.5	13.5	1.0
		T490-45-3N	0.66	15.7	12	11.8	11.8	5.6	7.5	1.3	1.7	1.9	2.5	13.5	1.0

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimen had d/ℓ_{eh} > 1.5

§§ Roof-level interior joints; all other specimens are exterior joints

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

	Study	Specimen	d' (in.)	d_b (in.)	$d_{b,sprt}$ (in.)	f_{cm} (psi)	f_y (ksi)	$f_{y,\,sprt}$ (ksi)	f_{yt} (ksi)	$f_{yt}A_v$ (kips)	f_{yto} (ksi)	h_b (in.)	h_c (in.)
	1	2	28	29	30	31	32	33	34	35	36	37	38
1	Bashandy (1996)	Exterior Joint	2.5	0.98	0.875	4290	64.8	65.3	45.1	90.2	45.1	18.0	15.0
2	Murakami et al. (1998)	No. 100	2.2	0.625	-	5700	53.7	-	113.8	44.7	113.8	15.7	11.8
		No. 101	2.2	0.625	-	5700	53.7	-	113.8	44.7	113.8	15.7	11.8
		B8-M	2.2	0.75	-	4280	74.1	-	113.8	44.7	113.8	15.7	11.8
		B7-M	2.2	0.75	-	4280	74.1	-	113.8	44.7	113.8	15.7	11.8
		No. 102 ‡	2.2	0.75	-	5700	137.1	-	113.8	44.7	113.8	15.7	11.8
		No. 103 ‡	2.2	0.75	-	5700	137.1	-	113.8	44.7	113.8	15.7	11.8
		No. 104 ‡	2.2	0.75	-	5700	137.1	-	113.8	44.7	113.8	15.7	11.8
		M8D16 ‡	2.8	0.625	-	4100	145.1	-	113.8	44.7	113.8	15.7	11.8
		M4D19 ‡	2.2	0.75	-	4100	145.1	-	113.8	44.7	113.8	15.7	11.8
		M3D19 ‡	2.2	0.75	-	4100	145.1	-	113.8	44.7	113.8	15.7	11.8
		M2D22 ‡	2.2	0.875	-	4100	141.1	-	113.8	44.7	113.8	15.7	11.8
3	Wallace et al. (1998)	BCEJ1 ‡‡	2.5	1	1.128	5190	67.0	67.0	67.0	160.8	67.0	24.0	18.0
4	Matsushima et al. (2000)	H	3.8	0.98	0.875	4770	79.9	75.5	57.6	38.2	126.4	18.9	15.7
		HS §	3.8	0.98	0.875	4770	79.9	75.5	57.6	38.2	126.4	18.9	15.7
5	Nakazawa et al. (2000)	J1	2.3	0.75	0.75	17400	103.0	99.5	184.9	103.8	184.9	14.2	14.2
		J2	2.3	0.75	0.75	17400	103.0	99.5	184.9	103.8	184.9	14.2	14.2
6	Tasai et al. (2000)	No. 6	2.5	1	0.875	7120	105.0	76.1	49.6	32.7	108.3	17.7	15.7
		No. 7	2.5	1	0.875	7120	105.0	76.1	49.6	32.7	108.3	17.7	15.7
7	Yoshida et al. (2000)	No. 1	1.8	0.75	0.75	5470	81.5	81.5	52.3	58.0	52.3	15.7	13.8
		No. 2	1.8	0.75	0.75	5470	81.5	81.5	52.3	58.0	52.3	15.7	13.8
		No. 3	1.8	0.75	0.75	4500	81.5	81.5	52.3	58.0	52.3	15.7	13.8
8	Takeuchi et al. (2001)	0-1	2.2	0.98	0.875	6400	64.5	80.2	141.4	93.3	141.4	17.7	15.7
		0-2	2.2	0.98	0.875	8830	85.0	80.2	141.4	93.3	141.4	17.7	15.7
		0-3	2.2	0.98	0.875	3520	54.7	80.2	141.4	93.3	141.4	17.7	15.7
		0-4	2.2	0.98	0.875	6400	64.5	80.2	141.4	93.3	141.4	17.7	15.7
		0-6	2.2	0.98	0.875	6440	104.1	80.2	141.4	93.3	141.4	17.7	15.7
		0-7	2.2	0.98	0.875	9000	104.1	80.2	141.4	93.3	141.4	17.7	15.7
9	Ishibashi et al. (2003) §§	T345-30-4S	2.2	0.75	0.75	4830	56.3	49.0	57.7	38.3	57.7	15.7	15.7
		T345-30-3N	2.2	0.75	0.75	4830	56.3	49.0	57.7	38.3	57.7	15.7	15.7
		T490-45-4S	2.2	0.75	0.75	7210	84.5	61.9	154.9	102.9	154.9	15.7	15.7
		T490-45-3N	2.2	0.75	0.75	7210	84.5	61.9	154.9	102.9	154.9	15.7	15.7

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimen had $d/\ell_{eh} > 1.5$

§§ Roof-level interior joints; all other specimens are exterior joints

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

	Study	Specimen	L_c (in.)	ℓ_{dt} # (in.)	ℓ_{dt}/d_b	ℓ_{dy} (in.)	ℓ_{dy}/d_b	ℓ_{eh} (in.)	ℓ_{eh}/d_b	ℓ_{ehy} (in.)	ℓ_{ehy}/d_b	ℓ_{eh}/h_c	ℓ_{eh}/ℓ_{dt}	ℓ_{eh}/ℓ_{dy}	ℓ_{eh}/ℓ_{ehy}
	1	2	39	40	41	42	43	44	45	46	47	48	49	50	51
1	Bashandy (1996)	Exterior Joint	96.0	9.6	9.8	16.1	16.4	11.5	11.7	7.8	8.0	0.76	1.19	0.71	1.46
2	Murakami et al. (1998)	No. 100	59.1	6.7	10.8	6.5	10.4	8.9	14.2	4.7	7.5	0.75	1.32	1.36	1.90
		No. 101	59.1	6.7	10.8	6.5	10.4	8.9	14.2	4.7	7.5	0.75	1.32	1.36	1.90
		B8-M	59.1	12.4	16.5	15.1	20.2	8.9	11.8	8.5	11.4	0.75	0.72	0.58	1.04
		B7-M	59.1	12.4	16.5	15.1	20.2	8.9	11.8	8.5	11.4	0.75	0.72	0.58	1.04
		No. 102 ‡	59.1	25.4	33.9	31.4	41.9	8.9	11.8	16.7	22.3	0.75	0.35	0.28	0.53
		No. 103 ‡	59.1	25.4	33.9	31.4	41.9	8.9	11.8	16.7	22.3	0.75	0.35	0.28	0.53
		No. 104 ‡	59.1	25.4	33.9	31.4	41.9	8.9	11.8	16.7	22.3	0.75	0.35	0.28	0.53
		M8D16 ‡	59.1	23.9	38.3	36.9	59.1	8.9	14.2	14.3	22.8	0.75	0.37	0.24	0.62
		M4D19 ‡	59.1	29.2	39.0	37.2	49.6	8.9	11.8	19.1	25.5	0.75	0.30	0.24	0.46
		M3D19 ‡	59.1	24.5	32.6	37.2	49.6	8.9	11.8	16.9	22.6	0.75	0.36	0.24	0.52
		M2D22 ‡	59.1	20.0	22.8	42.0	48.0	8.9	10.1	16.7	19.0	0.75	0.44	0.21	0.53
3	Wallace et al. (1998)	BCEJ1 ‡‡	120.0	10.9	10.9	16.0	16.0	13.9	13.9	8.9	8.9	0.77	1.28	0.87	1.56
4	Matsushima et al. (2000)	H	97.6	17.2	17.5	21.2	21.7	11.6	11.9	13.2	13.5	0.74	0.68	0.55	0.88
		HS §	97.6	17.2	17.5	21.2	21.7	7.9	8.0	13.2	13.5	0.50	0.46	0.37	0.60
5	Nakazawa et al. (2000)	J1	51.2	10.6	14.1	14.7	19.5	11.3	15.0	7.4	9.8	0.79	1.06	0.77	1.52
		J2	51.2	10.6	14.1	14.7	19.5	11.3	15.0	7.4	9.8	0.79	1.06	0.77	1.52
6	Tasai et al. (2000)	No. 6	85.4	26.7	26.7	27.6	27.6	11.8	11.8	18.9	18.9	0.75	0.44	0.43	0.62
		No. 7	85.4	18.9	18.9	27.6	27.6	11.8	11.8	15.9	15.9	0.75	0.63	0.43	0.74
7	Yoshida et al. (2000)	No. 1	78.7	11.4	15.3	15.9	21.2	10.2	13.6	9.1	12.1	0.74	0.89	0.64	1.13
		No. 2	78.7	11.4	15.3	15.9	21.2	10.2	13.6	9.1	12.1	0.74	0.89	0.64	1.13
		No. 3	78.7	12.0	16.0	17.5	23.4	10.2	13.6	9.5	12.6	0.74	0.85	0.58	1.08
8	Takeuchi et al. (2001)	0-1	57.1	10.5	10.7	13.5	13.8	10.4	10.6	7.9	8.0	0.66	0.99	0.77	1.32
		0-2	57.1	12.8	13.0	18.5	18.9	10.4	10.6	9.8	10.0	0.66	0.81	0.56	1.06
		0-3	57.1	10.3	10.5	13.2	13.4	10.4	10.6	7.5	7.7	0.66	1.01	0.79	1.38
		0-4	57.1	10.5	10.7	13.5	13.8	11.7	11.9	7.9	8.0	0.74	1.11	0.86	1.49
		0-6	57.1	20.8	21.2	27.7	28.2	10.4	10.6	15.2	15.5	0.66	0.50	0.38	0.69
		0-7	57.1	19.1	19.5	24.7	25.2	10.4	10.6	14.0	14.3	0.66	0.54	0.42	0.74
9	Ishibashi et al. (2003) §§	T345-30-4S	66.9	5.7	7.6	9.2	12.3	13.5	18.0	4.6	6.1	0.86	2.37	1.47	2.95
		T345-30-3N	66.9	5.7	7.6	9.2	12.3	13.5	18.0	4.6	6.1	0.86	2.37	1.47	2.95
		T490-45-4S	66.9	7.8	10.3	15.2	20.2	13.5	18.0	6.6	8.8	0.86	1.74	0.89	2.05
		T490-45-3N	66.9	7.8	10.3	15.2	20.2	13.5	18.0	6.6	8.8	0.86	1.74	0.89	2.05

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimen had d/ℓ_{eh} > 1.5

§§ Roof-level interior joints; all other specimens are exterior joints

\# ℓ_{dt} based on Eq. (5.2) in Ghimire et al. (2018)

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

	Study	Specimen	M_n (kip.in.)	M_{peak} (kip.in.)	M_{peak}/M_n	N	N_{arg} (kips)	N_{cbg} (kips)	N_{sb} (kips)	N_{sbg} (kips)	N_{splt} ◊	N_{total}	N_{tr}
	1	2	52	53	54	55	56	57	58	59	60	61	62
1	Bashandy (1996)	Exterior Joint	1443	1593	1.10	6	54.1	20.5	109.1	-	2	10	4
2	Murakami et al. (1998)	No. 100	859	1031	1.20	4	33.5	20.2	23.3	-	6	8	2
		No. 101	859	1066	1.24	4	33.5	20.2	44.9	-	6	8	2
		B8-M	1200	1395	1.16	4	33.5	17.5	45.2	-	6	8	2
		B7-M	1093	1242	1.14	4	33.5	17.5	45.2	-	6	8	2
		No. 102 ‡	2838	1957	0.69	4	33.5	20.2	30.9	-	6	8	2
		No. 103 ‡	2838	1524	0.54	4	33.5	20.2	51.3	-	6	8	2
		No. 104 ‡	2838	1793	0.63	4	33.5	20.2	39.0	-	6	8	2
		M8D16 ‡	2918	1793	0.61	2	44.7	18.4	31.8	35.8	6	8	4
		M4D19 ‡	2838	1688	0.59	4	33.5	17.1	35.7	-	6	8	2
		M3D19 ‡	2226	1676	0.75	4	33.5	17.1	35.7	-	6	8	2
		M2D22 ‡	1990	1324	0.67	6	33.5	17.1	40.0	-	6	8	2
3	Wallace et al. (1998)	BCEJ1 ‡‡	4448	4950	1.11	6	80.4	48.3	-	-	5	12	3
4	Matsushima et al. (2000)	H	2545	2205	0.87	4	136.8	27.7	-	-	8	6	4
		HS §	2545	2071	0.81	4	68.4	23.5	-	-	8	6	2
5	Nakazawa et al. (2000)	J1	2989	3391	1.13	8	173.5	38.6	64.5	73.4	6	12	8
		J2	2989	3344	1.12	8	173.5	38.6	79.3	90.3	6	12	8
6	Tasai et al. (2000)	No. 6	4388	2283	0.52	4	82.4	34.2	80.9	-	2	6	2
		No. 7	2359	1328	0.56	4	82.4	34.2	80.9	-	2	6	2
7	Yoshida et al. (2000)	No. 1	1818	1681	0.92	4	46.2	21.0	52.1	-	4	10	4
		No. 2	1818	1696	0.93	4	46.2	21.0	43.8	-	4	10	4
		No. 3	1797	1665	0.93	4	46.2	19.1	34.6	-	4	10	4
8	Takeuchi et al. (2001)	0-1	2237	2458	1.10	4	93.3	30.8	81.9	-	6	6	2
		0-2	2937	2897	0.99	4	93.3	36.1	96.2	-	6	6	2
		0-3	1821	1927	1.06	4	93.3	22.8	60.8	-	6	6	2
		0-4	2237	2591	1.16	4	93.3	32.3	81.9	-	6	6	2
		0-6	4390	3481	0.79	4	93.3	30.9	82.2	-	6	6	2
		0-7	4598	4106	0.89	4	93.3	36.5	97.1	-	6	6	2
9	Ishibashi et al. (2003) §§	T345-30-4S	1116	1401	1.25	4	51.0	25.2	29.6	42.0	4	6	4
		T345-30-3N	1116	1394	1.25	4	51.0	25.2	29.6	42.0	4	6	4
		T490-45-4S	1612	1925	1.19	4	170.8	30.8	36.2	51.3	4	6	4
		T490-45-3N	1612	1951	1.21	4	170.8	30.8	36.2	51.3	4	6	4

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimen had $d/\ell_{eh} > 1.5$

§§ Roof-level interior joints; all other specimens are exterior joints

◊ N_{splt} is used as N when calculating ℓ_{dy} [Eq. (4.6) in Ghimire et al. (2018)]

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

	Study	Specimen	N_{tro}	n	nT' (kips)	$n_{l,sprt}$	n_{sprt}	$P/A_g f'_c$	s_h/d_b	s'_{tr} (in.)	s_{tr} (in.)	s'_{tro} (in.)	s_{tro} (in.)	s_v/d_b	T_{anc} (kips)
	1	2	63	64	65	66	67	68	69	70	71	72	73	74	75
1	Bashandy (1996)	Exterior Joint	2	2	113.1	4	4	0.00	5.1	2.2	2.2	3.1	6.0	-	27.1
2	Murakami et al. (1998)	No. 100	4	4	79.8	4	12	0.04	3.5	1.6	3.1	1.5	3.0	-	8.4
		No. 101	4	4	82.6	4	12	0.04	3.5	1.6	3.1	1.5	3.0	-	8.4
		B8-M	4	3	113.7	4	12	0.06	4.3	1.6	3.1	1.5	3.0	-	11.2
		B7-M	4	3	111.2	4	12	0.06	4.3	1.6	3.1	1.5	3.0	-	11.2
		No. 102 ‡	4	4	166.4	4	12	0.04	2.9	1.6	3.1	1.5	3.0	-	8.4
		No. 103 ‡	4	4	129.6	4	12	0.04	2.9	1.6	3.1	1.5	3.0	-	8.4
		No. 104 ‡	4	4	152.5	4	12	0.04	2.9	1.6	3.1	1.5	3.0	-	8.4
		M8D16 ‡	4	8	221.1	4	12	0.06	3.5	2.8	1.8	1.5	3.0	3.2	5.6
		M4D19 ‡	4	4	151.9	4	12	0.06	2.9	1.6	3.1	1.5	3.0	-	8.4
		M3D19 ‡	4	3	144.2	4	12	0.06	4.3	1.6	3.1	1.5	3.0	-	11.2
		M2D22 ‡	4	2	112.7	4	12	0.06	7.4	1.6	3.1	1.5	3.0	-	16.8
3	Wallace et al. (1998)	BCEJ1 ‡‡	3	4	235.6	4	8	0.00	3.5	3.3	4.0	4.5	8.0	-	20.1
4	Matsushima et al. (2000)	H	8	3	164.1	4	12	0.11	5.1	1.0	4.7	1.8	3.9	-	45.6
		HS §	4	3	154.1	4	13	0.11	5.1	1.0	4.7	1.8	3.9	-	22.8
5	Nakazawa et al. (2000)	J1	12	6	308.3	8	12	0.00	3.7	0.8	3.0	0.8	2.0	3.4	28.9
		J2	12	6	304.1	8	12	0.00	3.7	0.8	3.0	0.8	2.0	3.4	28.9
6	Tasai et al. (2000)	No. 6	6	4	172.6	8	12	0.00	3.1	2.6	3.9	0.7	3.9	-	20.6
		No. 7	6	2	93.3	8	12	0.00	4.7	2.6	3.9	0.7	3.9	-	41.2
7	Yoshida et al. (2000)	No. 1	4	4	132.6	4	8	0.00	3.7	1.5	3.0	1.8	2.0	-	11.6
		No. 2	4	4	133.8	4	8	0.00	3.7	1.5	3.0	1.8	2.0	-	11.6
		No. 3	4	4	132.9	4	8	0.00	3.7	1.5	3.0	1.8	2.0	-	11.6
8	Takeuchi et al. (2001)	0-1	4	3	168.0	4	12	0.10	4.9	3.0	3.9	1.1	3.9	-	31.1
		0-2	4	3	198.6	4	12	0.10	4.9	3.0	3.9	1.1	3.9	-	31.1
		0-3	4	3	137.1	4	12	0.10	4.9	3.0	3.9	1.1	3.9	-	31.1
		0-4	4	3	177.1	4	12	0.10	4.9	3.0	3.9	1.1	3.9	-	31.1
		0-6	4	4	260.9	4	12	0.10	3.3	3.0	3.9	1.1	3.9	-	23.3
		0-7	4	4	293.8	4	12	0.10	3.3	3.0	3.9	1.1	3.9	-	23.3
9	Ishibashi et al. (2003) §§	T345-30-4S	4	3	93.2	4	8	0.00	7.5	0.6	5.1	0.6	3.5	7.5	17.0
		T345-30-3N	4	3	92.8	4	8	0.00	7.5	0.6	5.1	0.6	3.5	7.5	17.0
		T490-45-4S	6	3	133.2	4	8	0.00	7.5	0.6	5.1	0.6	2.4	7.5	25.7
		T490-45-3N	6	3	135.1	4	8	0.00	7.5	0.6	5.1	0.6	2.4	7.5	25.7

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimen had $d/\ell_{eh} > 1.5$

§§ Roof-level interior joints; all other specimens are exterior joints

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	T_h (kips)	T' (kips)	T'_{mod} (kips)	T'/T_{anc}	T'/T_h	T'_{mod}/T_h	t_{obs}/d_b	V_n (kips)	$V_{n,ACI352}$ (kips)	V_p (kips)
	1	2	76	77	78	79	80	81	82	83	84	85
1	Bashandy (1996)	Exterior Joint	51.2	56.5	53.7	2.09	1.10	1.05	0.0	141	130	96
2	Murakami et al. (1998)	No. 100	16.6	20.0	18.1	2.38	1.20	1.09	0.0	126	118	62
		No. 101	16.6	20.6	18.8	2.46	1.24	1.13	0.0	126	118	65
		B8-M	32.6	37.9	37.7	3.39	1.16	1.16	0.0	110	102	90
		B7-M	32.6	37.1	36.9	3.32	1.14	1.13	0.0	110	102	90
		No. 102 ‡	31.8	41.6	-	4.96	1.31	-	0.0	126	118	133
		No. 103 ‡	31.8	32.4	-	3.87	1.02	-	0.0	126	118	104
		No. 104 ‡	31.8	38.1	-	4.55	1.20	-	0.0	126	118	122
		M8D16 ‡	27.6	27.6	-	4.95	1.00	-	0.0	107	100	191
		M4D19 ‡	29.5	38.0	-	4.53	1.29	-	0.0	107	100	123
		M3D19 ‡	33.6	48.1	-	4.30	1.43	-	0.0	107	100	116
		M2D22 ‡	46.6	56.3	-	3.36	1.21	-	0.0	107	100	90
3	Wallace et al. (1998)	BCEJ1 ‡‡	52.9	58.9	55.3	2.93	1.11	1.04	0.0	280	280	194
4	Matsushima et al. (2000)	H	55.8	54.7	-	1.20	0.98	-	-	206	193	141
		HS §	39.0	51.4	-	2.25	1.32	-	-	206	193	133
5	Nakazawa et al. (2000)	J1	45.3	51.4	48.5	1.78	1.13	1.07	1.9	242	263	242
		J2	45.3	50.7	47.8	1.75	1.12	1.05	0.0	242	263	239
6	Tasai et al. (2000)	No. 6	52.3	43.2	-	2.09	0.83	-	1.9	251	235	146
		No. 7	63.0	46.7	-	1.13	0.74	-	1.9	251	235	78
7	Yoshida et al. (2000)	No. 1	35.9	33.1	32.6	2.87	0.92	0.91	0.0	144	144	111
		No. 2	35.9	33.4	32.9	2.89	0.93	0.92	0.0	144	144	112
		No. 3	35.9	33.2	32.9	2.88	0.93	0.92	0.0	131	131	112
8	Takeuchi et al. (2001)	0-1	51.0	56.0	54.0	1.80	1.10	1.06	0.0	238	223	125
		0-2	67.1	66.2	65.7	2.13	0.99	0.98	0.0	280	262	148
		0-3	43.2	45.7	43.7	1.47	1.06	1.01	0.0	177	166	103
		0-4	51.0	59.0	56.0	1.90	1.16	1.10	0.0	238	223	132
		0-6	57.0	65.2	-	2.80	1.14	-	0.0	239	224	200
		0-7	61.4	73.4	-	3.15	1.20	-	0.0	282	265	222
9	Ishibashi et al. (2003) §§	T345-30-4S	24.8	31.1	25.2	1.83	1.25	1.02	-	155	155	72
		T345-30-3N	24.8	30.9	25.0	1.82	1.25	1.01	-	155	155	72
		T490-45-4S	37.2	44.4	39.7	1.73	1.19	1.07	-	190	190	104
		T490-45-3N	37.2	45.0	40.3	1.76	1.21	1.08	-	190	190	106

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimen had $d/\ell_{eh} > 1.5$

§§ Roof-level interior joints; all other specimens are exterior joints

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

	Study	Specimen	V_p/V_n	$\delta_{0.8peak}$	δ_y	Υ_j	ψ_{cs} ##	ψ_o
	1	2	86	87	88	89	90	91
1	Bashandy (1996)	Exterior Joint	0.68	0.053	0.009	0.005	0.50	1.00
2	Murakami et al. (1998)	No. 100	0.49	0.080	-	-	0.71	1.25
		No. 101	0.51	0.083	-	-	0.71	1.25
		B8-M	0.82	0.060	-	-	0.67	1.25
		B7-M	0.82	0.070	-	-	0.67	1.25
		No. 102 ‡	1.05	0.040	-	-	0.79	1.25
		No. 103 ‡	0.82	0.055	-	-	0.79	1.25
		No. 104 ‡	0.97	0.050	-	-	0.79	1.25
		M8D16 ‡	1.78	0.040	-	-	0.86	1.25
		M4D19 ‡	1.15	0.040	-	-	0.79	1.25
		M3D19 ‡	1.08	0.040	-	-	0.67	1.25
		M2D22 ‡	0.84	0.020	-	-	0.44	1.25
3	Wallace et al. (1998)	BCEJ1 ‡‡	0.69	0.048	0.015	-	0.55	1.00
4	Matsushima et al. (2000)	H	0.69	0.035	-	0.022	0.59	1.25
		HS §	0.65	0.035	-	0.031	0.59	1.25
5	Nakazawa et al. (2000)	J1	1.00	0.050	0.020	0.001	0.73	1.00
		J2	0.99	0.058	0.020	0.001	0.73	1.00
6	Tasai et al. (2000)	No. 6	0.58	0.040	0.010	0.000	0.75	1.25
		No. 7	0.31	0.040	0.020	0.000	0.53	1.25
7	Yoshida et al. (2000)	No. 1	0.77	0.040	0.020	0.007	0.59	1.25
		No. 2	0.78	0.040	0.020	0.006	0.59	1.25
		No. 3	0.85	0.040	0.020	0.007	0.59	1.25
8	Takeuchi et al. (2001)	0-1	0.52	0.050	0.005	0.008	0.60	1.00
		0-2	0.53	0.033	0.010	-	0.60	1.00
		0-3	0.59	0.050	0.005	-	0.60	1.00
		0-4	0.55	0.050	0.006	0.003	0.60	1.00
		0-6	0.84	0.030	-	0.040	0.74	1.00
		0-7	0.79	0.030	-	-	0.74	1.00
9	Ishibashi et al. (2003) §§	T345-30-4S	0.47	0.065	0.010	0.009	0.42	1.25
		T345-30-3N	0.46	0.053	0.010	0.008	0.42	1.25
		T490-45-4S	0.55	0.053	0.010	0.010	0.42	1.25
		T490-45-3N	0.56	0.040	0.010	0.011	0.42	1.25

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimen had $d/\ell_{eh} > 1.5$

§§ Roof-level interior joints; all other specimens are exterior joints

\## ψ_{cs} is based on Table 5.1 in Ghimire et al. (2018)

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	Bar Size **	A_b (in.^{2})	A_{brg}/ A_b	A_{gross} / A_b	A_{hs} (in.^{2})	A_{Nc} (in.^{2})	A_{obs} / A_b	A_{tr} (in.^{2})	$A_{tr,l}$ (in.^{2})	$A_{tro,l}$ (in.^{2})	A_{tt} (in.^{2})	A_{tt}/ A_{hs}
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
10	Ishibashi and Inokuchi (2004) §§	2S-2	D29	1.02	-	-	3.06	1102	-	1.02	0.11	0.11	0.44	0.14
		2S-0 ¤	D29	1.02	-	-	3.06	1102	-	1.02	0.11	0.11	0.00	0.00
		WN-ST	D29	1.02	-	-	3.06	1102	-	1.02	0.11	0.11	1.11	0.36
11	Kiyohara et al. (2004)	No. 1	D29	1.00	4.1	6.7	4.00	933	2.6	0.79	0.20	0.20	0.79	0.20
		No. 2	D29	1.00	4.1	6.7	6.00	1017	2.6	0.79	0.20	0.20	0.79	0.13
		No. 3	D29	1.00	4.1	6.7	3.00	933	2.6	0.79	0.20	0.20	0.79	0.26
		No. 4	D29	1.00	4.1	6.7	4.00	1177	2.6	0.79	0.20	0.20	0.79	0.20
		No. 5 §	D29	1.00	4.1	6.7	4.00	704	2.6	0.79	0.20	0.20	0.79	0.20
12	Kiyohara et al. (2005)	No. 6	D29	1.00	4.1	6.7	7.00	1017	2.6	0.79	0.20	0.20	0.79	0.11
		No. 7	D29	1.00	4.1	6.7	7.00	1017	2.6	0.79	0.20	0.20	0.79	0.11
		No. 8 ‡	D29	1.00	4.1	6.7	7.00	1017	2.6	0.79	0.20	0.20	0.79	0.11
		No. 9	D29	1.00	4.1	6.7	7.00	1260	2.6	0.79	0.20	0.20	0.79	0.11
		No. 10 §	D29	1.00	4.1	6.7	7.00	787	2.6	0.79	0.20	0.20	0.79	0.11
		No. 11	D29	1.00	4.1	6.7	5.00	933	2.6	0.79	0.20	0.20	0.79	0.16
		No. 12	D29	1.00	4.1	6.7	6.00	1260	2.6	0.79	0.20	0.20	0.79	0.13
13	Kato (2005)	No. 1	D22	0.60	5.3	6.3	4.80	858	-	0.60	0.05	0.08	0.20	0.04
		No. 2	D22	0.60	3.6	6.3	4.80	858	2.7	0.60	0.05	0.08	0.20	0.04
14	Masuo et al. (2006)	AH12-2-45	D25	0.79	3.7	6.8	1.58	486	3.1	0.60	0.08	0.08	0.31	0.19
		AH12-2-40	D25	0.79	3.7	6.8	1.58	486	3.1	0.60	0.08	0.08	0.31	0.19
		AH12-2-45A §	D25	0.79	3.7	6.8	1.58	405	3.1	0.60	0.08	0.08	0.31	0.19
		AH8-2-45	D25	0.79	3.7	6.8	1.58	486	3.1	0.60	0.08	0.08	0.31	0.19
		AH12-8-45	D25	0.79	3.9	6.8	6.32	523	2.9	0.79	0.08	0.08	0.46	0.07
		AH12-8-40	D25	0.79	3.9	6.8	6.32	523	2.9	0.79	0.08	0.08	0.46	0.07
		AH12-8-45B	D25	0.79	3.9	6.8	6.32	523	2.9	0.79	0.08	0.08	0.92	0.15
		AH8-6-45	D25	0.79	3.9	6.8	4.74	523	2.9	0.60	0.08	0.08	0.46	0.10
15	Adachi and Masuo (2007)	J30-12-0	D25	0.79	3.9	6.4	3.16	625	2.5	0.60	0.11	0.11	0.44	0.14
		J30-12-P1 ‡‡	D25	0.79	3.9	6.4	3.16	625	2.5	0.60	0.11	0.11	0.44	0.14
		J30-12-P2 ‡‡	D25	0.79	3.9	6.4	3.16	625	2.5	0.60	0.11	0.11	0.44	0.14
		J60-12-0	D25	0.79	3.9	6.4	4.74	672	2.5	0.60	0.11	0.11	0.44	0.09
		J60-12-P1 ‡‡	D25	0.79	3.9	6.4	4.74	672	2.5	0.60	0.11	0.11	0.44	0.09
		J60-12-P2 ‡‡	D25	0.79	3.9	6.4	4.74	672	2.5	0.60	0.11	0.11	0.44	0.09

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

** Bar sizes are presented in SI as reported in the original studies (only Wallace et al. 1998 had bar sizes reported in in.-lb)

¤ Specimens did not contain confining reinforcement parallel to the headed bars within the joint region

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimens had $d/\ell_{eh} > 1.5$

§§ Roof-level interior joints; all other specimens are exterior joints

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	A_v (in.^{2})	b_b (in.)	b_c (in.)	b_j (in.)	$b_{j,ACI352}$ (in.)	c_{ch} (in.)	c_{ch}/d_b	c_o (in.)	c_o/d_b	c_{so} (in.)	c_{so}/d_b	d (in.)	d/ℓ_{eh}
1	2	3	15	16	17	18	19	20	21	22	23	24	25	26	27
10	Ishibashi and Inokuchi (2004) §§	2S-2	0.89	23.6	16	15.7	15.7	8.4	7.4	-	-	2.9	2.5	20.2	1.0
		2S-0 ¤	0.00	23.6	16	15.7	15.7	8.4	7.4	-	-	2.9	2.5	20.2	1.0
		WN-ST	1.33	23.6	16	15.7	15.7	8.4	7.4	-	-	2.9	2.5	20.2	1.0
11	Kiyohara et al. (2004)	No. 1	1.18	17.7	22	21.7	19.7	6.2	5.4	2.4	2.1	3.3	2.9	21.6	1.5
		No. 2	1.18	17.7	22	21.7	19.7	3.9	3.4	2.4	2.1	3.3	2.9	20.9	1.5
		No. 3	1.18	17.7	22	21.7	19.7	6.3	5.5	2.4	2.1	3.3	2.9	21.6	1.5
		No. 4	1.18	17.7	22	21.7	19.7	6.2	5.4	2.4	2.1	3.3	2.9	21.6	1.2
		No. 5 §	1.18	17.7	22	21.7	19.7	6.2	5.4	2.4	2.1	3.3	2.9	21.6	2.0
12	Kiyohara et al. (2005)	No. 6	1.18	17.7	22	21.7	19.7	3.3	2.9	2.4	2.1	3.3	2.9	20.9	1.5
		No. 7	1.18	17.7	22	21.7	19.7	3.3	2.9	2.4	2.1	3.3	2.9	20.9	1.5
		No. 8 ‡	1.18	17.7	22	21.7	19.7	3.3	2.9	2.4	2.1	3.3	2.9	20.9	1.5
		No. 9	1.18	17.7	22	21.7	19.7	3.3	2.9	2.4	2.1	3.3	2.9	20.9	1.2
		No. 10 §	1.18	17.7	22	21.7	19.7	3.3	2.9	2.4	2.1	3.3	2.9	20.9	1.9
		No. 11	1.18	17.7	22	21.7	19.7	3.3	2.9	2.4	2.1	3.3	2.9	21.6	1.5
		No. 12	1.18	17.7	22	21.7	19.7	3.9	3.4	2.4	2.1	3.3	2.9	20.9	1.2
13	Kato (2005)	No. 1	0.79	12.8	19	18.7	15.7	3.1	3.6	3.6	4.1	4.3	4.9	15.5	1.1
		No. 2	0.79	12.8	19	18.7	15.7	3.1	3.6	3.6	4.1	4.3	4.9	15.5	1.1
14	Masuo et al. (2006)	AH12-2-45	0.61	11.8	14	13.8	12.8	7.8	8.0	1.7	1.7	2.5	2.6	15.7	1.3
		AH12-2-40	0.61	11.8	14	13.8	12.8	7.8	8.0	1.7	1.7	2.5	2.6	15.7	1.3
		AH12-2-45A §	0.61	11.8	14	13.8	12.8	7.8	8.0	1.7	1.7	2.5	2.6	15.7	1.6
		AH8-2-45	0.61	11.8	14	13.8	12.8	7.8	8.0	1.7	1.7	2.5	2.6	15.7	1.3
		AH12-8-45	0.77	13.8	14	13.8	13.8	2.7	2.7	2.6	2.7	3.4	3.5	14.4	1.2
		AH12-8-40	0.77	13.8	14	13.8	13.8	2.7	2.7	2.6	2.7	3.4	3.5	14.4	1.2
		AH12-8-45B	0.77	13.8	14	13.8	13.8	2.7	2.7	2.6	2.7	3.4	3.5	14.4	1.2
		AH8-6-45	0.77	13.8	14	13.8	13.8	2.7	2.7	2.6	2.7	3.4	3.5	14.9	1.3
15	Adachi and Masuo (2007)	J30-12-0	0.89	13.8	18	17.7	15.7	3.1	3.2	2.7	2.7	3.4	3.5	15.7	1.3
		J30-12-P1	0.89	13.8	18	17.7	15.7	3.1	3.2	2.7	2.7	3.4	3.5	15.7	1.3
		J30-12-P2 ‡‡	0.89	13.8	18	17.7	15.7	3.1	3.2	-	-	-	-	15.7	1.3
		J60-12-0	0.89	13.8	18	17.7	15.7	2.6	2.7	2.7	2.7	3.4	3.5	15.0	1.3
		J60-12-P1	0.89	13.8	18	17.7	15.7	2.6	2.7	2.7	2.7	3.4	3.5	15.0	1.3
		J60-12-P2 ‡‡	0.89	13.8	18	17.7	15.7	2.6	2.7	-	-	-	-	15.0	1.3

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

¤ Specimens did not contain confining reinforcement parallel to the headed bars within the joint region

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimens had d/ℓ_{eh} > 1.5

§§ Roof-level interior joints; all other specimens are exterior joints

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	d' (in.)	d_b (in.)	$d_{b,sprt}$ (in.)	f_{cm} (psi)	f_y (ksi)	$f_{y,sprt}$ (ksi)	f_{yt} (ksi)	$f_{yt} A_v$ (kips)	f_{yto} (ksi)	h_b (in.)	h_c (in.)
	1	2	28	29	30	31	32	33	34	35	36	37	38
10	Ishibashi and Inokuchi (2004) §§	2S-2	3.4	1.14	1.14	5180	77.1	77.1	60.2	53.3	139.3	23.6	23.6
		2S-0 ¤	3.4	1.14	1.14	5180	77.1	77.1	0.0	0.0	139.3	23.6	23.6
		WN-ST	3.4	1.14	1.14	5420	77.1	77.1	139.3	185.2	139.3	23.6	23.6
11	Kiyohara et al. (2004)	No. 1	2.0	1.14	1	13820	103.0	103.1	124.0	146.3	124.0	23.6	21.7
		No. 2	2.8	1.14	1	21520	103.0	103.1	124.0	146.3	124.0	23.6	21.7
		No. 3	2.0	1.14	1	6440	103.0	103.1	124.0	146.3	124.0	23.6	21.7
		No. 4	2.0	1.14	1	13820	103.0	103.1	124.0	146.3	124.0	23.6	21.7
		No. 5 §	2.0	1.14	1	13820	103.0	103.1	124.0	146.3	124.0	23.6	21.7
12	Kiyohara et al. (2005)	No. 6	2.8	1.14	1	15420	149.9	102.2	119.0	140.5	119.0	23.6	21.7
		No. 7	2.8	1.14	1	20130	149.9	102.2	119.0	140.5	119.0	23.6	21.7
		No. 8 ‡	2.8	1.14	1	6870	149.9	102.2	119.0	140.5	119.0	23.6	21.7
		No. 9	2.8	1.14	1	15360	149.9	102.2	119.0	140.5	119.0	23.6	21.7
		No. 10 §	2.8	1.14	1	15660	149.9	102.2	119.0	140.5	119.0	23.6	21.7
		No. 11	2.0	1.14	1	15000	100.1	102.2	119.0	140.5	119.0	23.6	21.7
		No. 12	2.8	1.14	1	15230	100.1	102.2	119.0	140.5	119.0	23.6	21.7
13	Kato (2005)	No. 1	2.3	0.875	0.875	8820	75.5	99.3	113.8	89.4	113.8	17.7	18.7
		No. 2	2.3	0.875	0.875	10270	73.2	99.3	113.8	89.4	113.8	17.7	18.7
14	Masuo et al. (2006)	AH12-2-45	2.0	0.98	0.875	18820	148.0	83.2	155.3	95.3	155.3	17.7	17.7
		AH12-2-40	2.0	0.98	0.875	18820	148.0	83.2	155.3	95.3	155.3	17.7	15.7
		AH12-2-45A §	2.0	0.98	0.875	18820	148.0	83.2	155.3	95.3	155.3	17.7	17.7
		AH8-2-45	2.0	0.98	0.875	13140	148.0	83.2	155.3	95.3	155.3	17.7	17.7
		AH12-8-45	3.3	0.98	1	18820	92.0	79.6	155.3	119.2	155.3	17.7	17.7
		AH12-8-40	3.3	0.98	1	18820	92.0	79.6	155.3	119.2	155.3	17.7	15.7
		AH12-8-45B	3.3	0.98	1	18820	92.0	79.6	155.3	119.2	155.3	17.7	17.7
		AH8-6-45	2.8	0.98	0.875	13140	92.0	83.2	155.3	119.2	155.3	17.7	17.7
15	Adachi and Masuo (2007)	J30-12-0	2.0	0.98	0.875	4480	76.0	60.0	54.8	48.6	109.9	17.7	17.7
		J30-12-P1	2.0	0.98	0.875	4480	76.0	60.0	54.8	48.6	109.9	17.7	17.7
		J30-12-P2 ‡‡	2.0	0.98	0.875	4480	76.0	60.0	54.8	48.6	109.9	17.7	17.7
		J60-12-0	2.8	0.98	0.875	9150	76.0	60.0	54.8	48.6	109.9	17.7	17.7
		J60-12-P1	2.8	0.98	0.875	9150	76.0	60.0	54.8	48.6	109.9	17.7	17.7
		J60-12-P2 ‡‡	2.8	0.98	0.875	9150	76.0	60.0	54.8	48.6	109.9	17.7	17.7

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

¤ Specimens did not contain confining reinforcement parallel to the headed bars within the joint region

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimens had d/ℓ_{eh} > 1.5

§§ Roof-level interior joints; all other specimens are exterior joints

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	l_c (in.)	ℓ_{dt} # (in.)	ℓ_{dt}/d_b	ℓ_{dy} (in.)	ℓ_{dy}/d_b	ℓ_{eh} (in.)	ℓ_{eh}/d_b	ℓ_{ehy} (in.)	ℓ_{ehy}/d_b	ℓ_{eh}/h_c	ℓ_{eh}/ℓ_{dt}	ℓ_{eh}/ℓ_{dy}	ℓ_{eh}/ℓ_{ehy}
	1	2	39	40	41	42	43	44	45	46	47	48	49	50	51
10	Ishibashi and Inokuchi (2004) §§	2S-2	100.4	16.9	14.9	22.8	20.0	20.5	18.0	13.1	11.5	0.87	1.21	0.90	1.56
		2S-0 ¤	100.4	19.1	16.8	22.8	20.0	20.5	18.0	14.9	13.0	0.87	1.07	0.90	1.38
		WN-ST	100.4	14.4	12.6	22.4	19.6	20.5	18.0	11.8	10.3	0.87	1.42	0.92	1.74
11	Kiyohara et al. (2004)	No. 1	118.1	16.4	14.3	24.3	21.3	14.4	12.6	12.3	10.7	0.66	0.88	0.59	1.17
		No. 2	118.1	19.1	16.8	20.6	18.0	14.4	12.6	13.4	11.7	0.66	0.75	0.70	1.08
		No. 3	118.1	17.9	15.7	31.7	27.8	14.4	12.6	14.0	12.3	0.66	0.80	0.45	1.02
		No. 4	118.1	16.4	14.3	24.3	21.3	18.1	15.9	12.3	10.7	0.84	1.11	0.75	1.48
		No. 5 §	118.1	16.4	14.3	24.3	21.3	10.8	9.5	12.3	10.7	0.50	0.66	0.45	0.88
12	Kiyohara et al. (2005)	No. 6	118.1	32.4	28.4	39.1	34.3	14.4	12.6	22.2	19.4	0.66	0.44	0.37	0.65
		No. 7	118.1	30.3	26.6	35.8	31.4	14.4	12.6	20.8	18.3	0.66	0.47	0.40	0.69
		No. 8 ‡	118.1	39.7	34.8	50.3	44.1	14.4	12.6	26.7	23.5	0.66	0.36	0.29	0.54
		No. 9	118.1	32.5	28.5	39.1	34.3	18.1	15.9	22.2	19.5	0.84	0.56	0.46	0.82
		No. 10 §	118.1	32.3	28.3	38.9	34.1	10.8	9.5	22.1	19.4	0.50	0.34	0.28	0.49
		No. 11	118.1	20.3	17.8	22.6	19.8	14.4	12.6	14.6	12.8	0.66	0.71	0.64	0.99
		No. 12	118.1	20.3	17.8	22.4	19.7	18.1	15.9	14.0	12.3	0.84	0.89	0.81	1.29
13	Kato (2005)	No. 1	88.6	13.1	15.0	13.8	15.8	14.2	16.2	8.3	9.4	0.76	1.08	1.02	1.72
		No. 2	88.6	12.3	14.0	12.3	14.0	14.2	16.2	7.7	8.8	0.76	1.16	1.16	1.83
14	Masuo et al. (2006)	AH12-2-45	59.1	13.3	13.6	30.9	31.6	11.8	12.0	12.3	12.6	0.66	0.88	0.38	0.95
		AH12-2-40	59.1	13.3	13.6	30.9	31.6	11.8	12.0	12.3	12.6	0.75	0.88	0.38	0.95
		AH12-2-45A §	59.1	13.3	13.6	30.9	31.6	9.8	10.0	12.3	12.6	0.55	0.73	0.32	0.79
		AH8-2-45	59.1	14.6	14.9	34.8	35.5	11.8	12.0	13.4	13.7	0.66	0.81	0.34	0.88
		AH12-8-45	59.1	16.2	16.5	15.6	15.9	11.8	12.0	11.2	11.4	0.66	0.73	0.75	1.05
		AH12-8-40	59.1	16.2	16.5	15.6	15.9	11.8	12.0	11.2	11.4	0.75	0.73	0.75	1.05
		AH12-8-45B	59.1	14.5	14.8	15.6	15.9	11.8	12.0	10.9	11.1	0.66	0.81	0.75	1.08
		AH8-6-45	59.1	17.1	17.5	18.0	18.3	11.8	12.0	12.1	12.3	0.66	0.69	0.65	0.97
15	Adachi and Masuo (2007)	J30-12-0	59.1	16.7	17.0	20.2	20.6	11.8	12.0	12.0	12.3	0.66	0.70	0.58	0.98
		J30-12-P1	59.1	16.7	17.0	20.2	20.6	11.8	12.0	12.0	12.3	0.66	0.70	0.58	0.98
		J30-12-P2 ‡‡	59.1	16.7	17.0	20.2	20.6	11.8	12.0	12.0	12.3	0.66	0.70	0.58	0.98
		J60-12-0	59.1	15.6	15.9	15.3	15.6	11.8	12.0	10.9	11.1	0.66	0.75	0.77	1.08
		J60-12-P1	59.1	15.6	15.9	15.3	15.6	11.8	12.0	10.9	11.1	0.66	0.75	0.77	1.08
		J60-12-P2 ‡‡	59.1	15.6	15.9	15.3	15.6	11.8	12.0	10.9	11.1	0.66	0.75	0.77	1.08

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

¤ Specimens did not contain confining reinforcement parallel to the headed bars within the joint region

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimens had $d/\ell_{eh} > 1.5$

§§ Roof-level interior joints; all other specimens are exterior joints

\# ℓ_{dt} based on Eq. (5.2) in Ghimire et al. (2018)

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	M_n (kip.in.)	M_{peak} (kip.in.)	M_{peak} / M_n	N	N_{arg} (kips)	N_{cbg} (kips)	N_{sb} (kips)	N_{sbg} (kips)	N_{splt} ◊	N_{total}	N_{tr}
	1	2	52	53	54	55	56	57	58	59	60	61	62
10	Ishibashi and Inokuchi (2004) §§	2S-2	5740	6272	1.09	4	118.6	42.8	-	-	4	8	4
		2S-0 ¤	5740	6165	1.07	0	92.0	42.8	-	-	4	0	0
		WN-ST	5953	6272	1.05	10	246.3	43.8	-	-	4	12	10
11	Kiyohara et al. (2004)	No. 1	8500	9833	1.16	4	147.9	61.9	125.6	-	8	6	2
		No. 2	12310	11746	0.95	4	196.7	67.4	125.6	146.5	8	6	4
		No. 3	6189	6856	1.11	4	147.9	49.7	100.8	-	8	6	2
		No. 4	8500	10524	1.24	4	147.9	68.5	125.6	-	8	6	2
		No. 5 §	8500	8876	1.04	4	98.4	55.0	125.6	-	6	6	2
12	Kiyohara et al. (2005)	No. 6	19538	13792	0.71	4	188.9	67.5	125.6	146.5	10	6	4
		No. 7	20094	14350	0.71	4	188.9	67.5	125.6	146.5	10	6	4
		No. 8 ‡	18015	9647	0.54	4	188.9	55.9	104.1	121.4	10	6	4
		No. 9	19529	16264	0.83	4	188.9	73.3	125.6	146.5	10	6	4
		No. 10 §	19575	12836	0.66	4	94.4	61.5	125.6	146.5	8	6	2
		No. 11	10265	10391	1.01	4	142.1	61.9	125.6	-	10	6	2
		No. 12	11747	13686	1.17	4	188.9	73.3	125.6	146.5	10	6	4
13	Kato (2005)	No. 1	5273	5744	1.09	4	173.6	54.7	126.6	141.6	6	16	12
		No. 2	5391	5582	1.04	4	173.6	58.2	111.1	124.2	6	16	12
14	Masuo et al. (2006)	AH12-2-45	3543	4032	1.14	4	95.3	35.5	81.8	-	5	8	4
		AH12-2-40	3543	3772	1.06	4	95.3	35.5	81.8	-	5	8	4
		AH12-2-45A §	3543	3998	1.13	4	71.5	32.8	81.8	-	5	8	2
		AH8-2-45	3480	3603	1.04	4	95.3	35.5	81.8	-	5	8	4
		AH12-8-45	7284	8064	1.11	6	168.4	39.0	110.6	123.1	6	10	6
		AH12-8-40	7284	7883	1.08	6	168.4	39.0	110.6	123.1	6	10	6
		AH12-8-45B	7284	8550	1.17	12	216.1	39.0	110.6	123.1	6	10	10
		AH8-6-45	5654	6302	1.11	6	168.4	39.0	110.6	123.1	6	10	6
15	Adachi and Masuo (2007)	J30-12-0	3233	3490	1.08	4	72.6	31.2	73.7	-	6	8	4
		J30-12-P1	3233	3513	1.09	4	72.6	31.2	73.7	-	6	8	4
		J30-12-P2 ‡‡	3233	3569	1.10	4	72.6	40.7	-	-	6	8	4
		J60-12-0	4781	4845	1.01	4	72.6	47.9	105.3	117.2	6	8	4
		J60-12-P1	4781	5139	1.07	4	72.6	47.9	105.3	117.2	6	8	4
		J60-12-P2 ‡‡	4781	5320	1.11	4	72.6	62.5	-	-	6	8	4

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

¤ Specimens did not contain confining reinforcement parallel to the headed bars within the joint region

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimens had $d/\ell_{eh} > 1.5$

§§ Roof-level interior joints; all other specimens are exterior joints

◊ N_{splt} is used as N when calculating ℓ_{dy} [Eq. (4.6) in Ghimire et al. (2018)]

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	N_{tro}	n	nT' (kips)	$n_{l,sprt}$	n_{sprt}	$P/A_g f'_c$	s_h/d_b	s'_{tr} (in.)	s_{tr} (in.)	s'_{tro} (in.)	s_{tro} (in.)	s_v/d_b	T_{anc} (kips)
	1	2	63	64	65	66	67	68	69	70	71	72	73	74	75
10	Ishibashi and Inokuchi (2004) §§	2S-2	6	3	258.1	4	8	0.00	7.4	1.8	4.8	1.8	3.5	7.4	39.5
		2S-0 ¤	6	3	253.7	0	8	0.00	7.4	-	-	1.8	3.5	7.4	30.7
		WN-ST	6	3	248.9	4	8	0.00	7.4	1.8	1.8	1.8	3.5	7.4	82.1
11	Kiyohara et al. (2004)	No. 1	4	4	476.6	4	16	0.00	5.4	3.9	5.9	2.0	3.9	-	37.0
		No. 2	4	6	589.7	4	16	0.00	5.4	2.0	3.9	2.0	3.9	3.4	32.8
		No. 3	4	3	342.3	4	16	0.00	5.5	3.9	5.9	2.0	3.9	-	49.3
		No. 4	4	4	510.1	4	16	0.00	5.4	3.9	5.9	2.0	3.9	-	37.0
		No. 5 §	2	4	430.2	4	16	0.00	5.4	3.9	5.9	2.0	3.9	-	24.6
12	Kiyohara et al. (2005)	No. 6	4	7	740.9	4	20	0.00	2.9	2.0	3.9	2.0	3.9	3.4	27.0
		No. 7	4	7	749.5	4	20	0.00	2.9	2.0	3.9	2.0	3.9	3.4	27.0
		No. 8 ‡	4	7	562.0	4	20	0.00	2.9	2.0	3.9	2.0	3.9	3.4	27.0
		No. 9	4	7	874.0	4	20	0.00	2.9	2.0	3.9	2.0	3.9	3.4	27.0
		No. 10 §	2	7	688.2	4	20	0.00	2.9	2.0	3.9	2.0	3.9	3.4	13.5
		No. 11	4	5	506.4	4	20	0.00	2.9	3.9	5.9	2.0	3.9	-	28.4
		No. 12	4	6	699.4	4	20	0.00	5.4	2.0	3.9	2.0	3.9	3.4	31.5
13	Kato (2005)	No. 1	12	8	395.0	12	12	0.00	3.6	2.4	2.4	1.6	2.4	3.8	21.7
		No. 2	12	8	363.9	12	12	0.00	3.6	2.4	2.4	1.6	2.4	3.8	21.7
14	Masuo et al. (2006)	AH12-2-45	4	2	266.1	4	8	0.02	8.0	2.0	3.3	2.0	2.4	-	47.7
		AH12-2-40	4	2	249.0	4	8	0.02	8.0	2.0	3.3	2.0	2.4	-	47.7
		AH12-2-45A §	4	2	263.9	4	8	0.02	8.0	2.0	3.3	2.0	2.4	-	35.8
		AH8-2-45	4	2	242.1	4	10	0.02	8.0	2.0	3.3	2.0	2.4	-	47.7
		AH12-8-45	8	8	643.7	4	12	0.02	3.2	1.3	2.8	2.0	2.0	2.7	21.1
		AH12-8-40	8	8	629.3	4	12	0.02	3.2	1.3	2.8	2.0	2.0	2.7	21.1
		AH12-8-45B	8	8	682.5	4	12	0.02	3.2	1.3	2.8	2.0	2.0	2.7	27.0
		AH8-6-45	8	6	486.1	4	12	0.02	3.2	1.3	2.8	2.0	2.0	2.7	28.1
15	Adachi and Masuo (2007)	J30-12-0	4	4	259.2	4	12	0.06	3.2	2.0	3.3	2.4	3.1	-	18.2
		J30-12-P1	4	4	260.9	4	12	0.06	3.2	2.0	3.3	2.4	3.1	-	18.2
		J30-12-P2 ‡‡	4	4	265.0	4	12	0.06	3.2	2.0	3.3	2.4	3.1	-	18.2
		J60-12-0	4	6	365.0	4	12	0.04	3.2	1.7	2.4	2.4	3.1	2.7	12.1
		J60-12-P1	4	6	387.1	4	12	0.04	3.2	1.7	2.4	2.4	3.1	2.7	12.1
		J60-12-P2 ‡‡	4	6	400.7	4	12	0.04	3.2	1.7	2.4	2.4	3.1	2.7	12.1

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

¤ Specimens did not contain confining reinforcement parallel to the headed bars within the joint region

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimens had $d/\ell_{eh} > 1.5$

§§ Roof-level interior joints; all other specimens are exterior joints

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	T_h (kips)	T' (kips)	T'_{mod} (kips)	T'/T_{anc}	T'/T_h	T'_{mod}/T_h	t_{obs}/d_b	V_n (kips)	$V_{n,ACI352}$ (kips)	V_p (kips)
	1	2	76	77	78	79	80	81	82	83	84	85
10	Ishibashi and Inokuchi (2004) [§§]	2S-2	78.7	86.0	80.6	2.18	1.09	1.02	-	321	321	196
		2S-0 [¤]	78.7	84.6	80.9	2.76	1.07	1.03	-	321	321	192
		WN-ST	78.7	83.0	75.8	1.01	1.05	0.96	-	329	329	186
11	Kiyohara et al. (2004)	No. 1	103.0	119.2	117.0	3.22	1.16	1.14	2.0	563	601	393
		No. 2	103.0	98.3	97.3	3.00	0.95	0.94	2.0	563	626	490
		No. 3	103.0	114.1	113.8	2.31	1.11	1.11	2.0	452	410	284
		No. 4	103.0	127.5	121.5	3.45	1.24	1.18	2.0	563	601	421
		No. 5 [§]	91.8	107.6	-	4.37	1.17	-	2.0	563	601	355
12	Kiyohara et al. (2005)	No. 6	97.6	105.8	-	3.92	1.08	-	2.0	563	626	624
		No. 7	103.7	107.1	-	3.97	1.03	-	2.0	563	626	628
		No. 8 [‡]	81.2	80.3	-	2.98	0.99	-	2.0	466	424	480
		No. 9	122.5	124.9	-	4.63	1.02	-	2.0	563	626	736
		No. 10 [§]	74.3	98.3	-	7.29	1.32	-	2.0	563	626	580
		No. 11	98.8	101.3	-	3.56	1.03	-	2.0	563	626	418
		No. 12	100.0	116.6	113.0	3.70	1.17	1.13	2.0	563	626	584
13	Kato (2005)	No. 1	45.3	49.4	45.4	2.28	1.09	1.00	0.0	394	332	330
		No. 2	43.9	45.5	41.0	2.10	1.04	0.93	1.9	420	358	301
14	Masuo et al. (2006)	AH12-2-45	111.6	133.1	-	2.79	1.19	-	1.9	293	333	198
		AH12-2-40	111.6	124.5	-	2.61	1.12	-	1.9	260	296	185
		AH12-2-45A [§]	93.7	131.9	-	3.69	1.41	-	1.9	293	333	196
		AH8-2-45	103.0	121.1	-	2.54	1.18	-	1.9	293	312	181
		AH12-8-45	72.7	80.5	80.0	3.82	1.11	1.10	1.9	293	359	507
		AH12-8-40	72.7	78.7	78.2	3.74	1.08	1.08	1.9	260	319	496
		AH12-8-45B	72.7	85.3	84.6	3.16	1.17	1.16	1.9	293	359	538
		AH8-6-45	70.8	81.0	-	2.89	1.14	-	1.9	293	336	379
15	Adachi and Masuo (2007)	J30-12-0	58.7	64.8	-	3.57	1.10	-	1.9	252	224	200
		J30-12-P1	58.7	65.2	-	3.59	1.11	-	1.9	252	224	201
		J30-12-P2 [‡‡]	58.7	66.3	-	3.65	1.13	-	1.9	252	224	205
		J60-12-0	60.0	60.8	60.2	5.02	1.01	1.00	1.9	360	320	283
		J60-12-P1	60.0	64.5	63.9	5.33	1.07	1.07	1.9	360	320	300
		J60-12-P2 [‡‡]	60.0	66.8	66.2	5.52	1.11	1.10	1.9	360	320	311

[*] Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

[¤] Specimens did not contain confining reinforcement parallel to the headed bars within the joint region

[‡] Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

[‡‡] Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

[§] Specimens had $d/\ell_{eh} > 1.5$

[§§] Roof-level interior joints; all other specimens are exterior joints

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

	Study	Specimen	V_p/V_n	$\delta_{0.8peak}$	δ_y	Υ_j	ψ_{cs} ##	ψ_o
	1	2	86	87	88	89	90	91
10	Ishibashi and Inokuchi (2004) §§	2S-2	0.61	0.030	0.010	0.004	0.49	1.25
		2S-0 ¤	0.60	0.030	0.010	0.003	0.55	1.25
		WN-ST	0.57	0.030	0.010	0.005	0.42	1.25
11	Kiyohara et al. (2004)	No. 1	0.70	0.040	0.017	0.018	0.57	1.00
		No. 2	0.87	0.040	0.017	0.018	0.74	1.00
		No. 3	0.63	0.040	0.013	0.011	0.51	1.00
		No. 4	0.75	0.080	0.017	0.008	0.57	1.00
		No. 5 §	0.63	0.033	0.015	0.018	0.57	1.00
12	Kiyohara et al. (2005)	No. 6	1.11	0.040	0.040	0.012	0.79	1.00
		No. 7	1.12	0.040	0.040	0.013	0.79	1.00
		No. 8 ‡	1.03	0.040	0.040	0.017	0.79	1.00
		No. 9	1.31	0.040	0.040	0.012	0.79	1.00
		No. 10 §	1.03	0.040	0.040	0.013	0.79	1.00
		No. 11	0.74	0.040	0.018	0.014	0.74	1.00
		No. 12	1.04	0.040	0.020	0.008	0.74	1.00
13	Kato (2005)	No. 1	0.84	0.040	0.013	-	0.82	1.00
		No. 2	0.72	0.080	0.110	-	0.82	1.00
14	Masuo et al. (2006)	AH12-2-45	0.68	0.030	0.013	-	0.44	1.00
		AH12-2-40	0.71	0.028	0.019	-	0.44	1.00
		AH12-2-45A §	0.67	0.030	0.016	-	0.44	1.00
		AH8-2-45	0.62	0.030	0.020	-	0.44	1.00
		AH12-8-45	1.73	0.040	0.010	-	0.85	1.00
		AH12-8-40	1.90	0.040	0.012	-	0.85	1.00
		AH12-8-45B	1.84	0.040	0.012	-	0.76	1.00
		AH8-6-45	1.29	0.030	0.012	-	0.82	1.00
15	Adachi and Masuo (2007)	J30-12-0	0.79	0.032	-	-	0.74	1.00
		J30-12-P1	0.80	0.045	-	-	0.74	1.00
		J30-12-P2 ‡‡	0.81	0.062	-	-	0.74	1.00
		J60-12-0	0.79	0.033	-	-	0.83	1.00
		J60-12-P1	0.83	0.034	-	-	0.83	1.00
		J60-12-P2 ‡‡	0.86	0.067	-	-	0.83	1.00

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

¤ Specimens did not contain confining reinforcement parallel to the headed bars within the joint region

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimens had $d/\ell_{eh} > 1.5$

§§ Roof-level interior joints; all other specimens are exterior joints

ψ_{cs} is based on Table 5.1 in Ghimire et al. (2018)

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	Bar Size **	A_b (in.^{2})	A_{brg} / A_b	A_{gross} / A_b	A_{hs} (in.^{2})	A_{Nc} (in.^{2})	A_{obs}/ A_b	A_{tr} (in.^{2})	$A_{tr,l}$ (in.^{2})	$A_{tro,l}$ (in.^{2})	A_{tt} (in.^{2})	A_{tt}/ A_{hs}
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
16	Chun et al. (2007)	JM-1 ◊◊	D22	0.60	2.9	3.9	2.40	1162	2.2	0.60	0.11	0.11	0.22	0.09
		JM-2 ◊◊	D22	0.60	2.9	3.9	4.80	1206	2.2	0.60	0.11	0.11	0.22	0.05
		WM ¤, ◊◊	D32	1.27	2.9	3.9	6.35	1788	2.2	1.27	0.11	0.11	0.00	0.00
		JM-No.11-1a	D36	1.56	2.7	4.9	4.68	1331	2.2	1.56	0.20	0.20	1.20	0.26
		JM-No.11-1b	D36	1.56	2.7	4.9	4.68	1331	2.2	1.56	0.20	0.20	1.20	0.26
17	Ishida et al. (2007)	P1 ‡‡	D22	0.60	-	-	4.20	562	-	0.79	0.11	0.11	0.89	0.21
		P2 ‡‡	D22	0.60	-	-	4.20	562	-	0.79	0.11	0.11	0.89	0.21
		P3 ‡‡	D22	0.60	-	-	4.20	562	-	0.79	0.11	0.11	0.89	0.21
		P4 ‡‡	D22	0.60	-	-	5.40	562	-	0.79	0.11	0.11	0.89	0.16
18	Tazaki et al. (2007)	E1	D16	0.31	6.9	7.9	1.85	379	-	0.44	0.05	0.04	0.20	0.11
		E2 §	D16	0.31	6.9	7.9	1.85	240	-	0.44	0.05	0.04	0.10	0.05
19	Lee and Yu (2009)	W0-M1	D22	0.60	3.2	6.1	2.40	868	2.9	0.60	0.11	0.11	0.33	0.14
		W150-M1	D22	0.60	3.2	6.1	2.40	868	2.9	0.60	0.11	0.11	0.33	0.14
		W0-M2	D22	0.60	3.2	6.1	2.40	868	2.9	0.60	0.11	0.11	0.33	0.14
		W150-M2	D22	0.60	3.2	6.1	2.40	868	2.9	0.60	0.11	0.11	0.33	0.14
20	Kang et al. (2010)	JD §	D19	0.44	2.6	3.6	1.77	598	-	0.79	0.11	0.11	0.44	0.25
21	Kang et al. (2012)	JH-R1	D19	0.44	5.3	6.3	1.76	505	-	0.44	0.11	0.11	0.33	0.19
		JH-R2	D19	0.44	5.3	6.3	1.76	531	-	0.44	0.11	0.11	0.33	0.19
22	Chun and Shin (2014) ◊◊	M0.7S ‡	D16	0.44	4.0	5.0	1.76	324	-	0.71	0.17	0.20	0.51	0.29
		M1.0S	D16	0.44	4.0	5.0	1.76	324	-	0.71	0.20	0.20	1.02	0.58
		M1.5S §	D16	0.44	4.0	5.0	1.76	324	-	0.71	0.20	0.20	1.02	0.58
		M2.0S §	D16	0.44	4.0	5.0	1.76	324	-	0.71	0.20	0.20	1.02	0.58
		M2.5S §	D16	0.44	4.0	5.0	1.76	324	-	0.71	0.20	0.20	1.02	0.58
		M0.7U ‡	D16	0.44	4.0	5.0	1.76	324	-	0.71	0.11	0.20	0.33	0.19
		M1.0U	D16	0.44	4.0	5.0	1.76	324	-	0.71	0.11	0.20	0.66	0.38
23	Dhake et al. (2015)	J4 ¤	D12	0.18	4.0	5.0	0.35	105	-	0.35	0.05	0.05	0.00	0.00
		J5 ¤	D12	0.18	4.0	5.0	0.35	71	-	0.35	0.05	0.05	0.00	0.00
		J9	D12	0.18	4.0	5.0	0.35	105	-	0.35	0.05	0.05	0.20	0.56

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

** Bar sizes are presented in SI as reported in the original studies (only Wallace et al. 1998 had bar sizes reported in in.-lb)

¤ Specimens did not contain confining reinforcement parallel to the headed bars within the joint region

◊◊ Heads contained obstruction with diameter d_{obs} of $1.5d_b$ and length $t_{obs} \leq 0.6d_b$ for ≥ No.8 (D25) bars or ≤ smaller of 0.6 in. and $0.75d_b$ for < No.8 (D25) bars. Therefore, the obstruction is not considered to detract from the net bearing area of the head.

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimens had $d/\ell_{eh} > 1.5$

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	A_v (in.^{2})	b_b (in.)	b_c (in.)	b_j (in.)	$b_{j,ACI\ 352}$ (in.)	c_{ch} (in.)	c_{ch}/d_b	c_o (in.)	c_o/d_b	c_{so} (in.)	c_{so}/d_b	d (in.)	d/ℓ_{eh}
	1	2	15	16	17	18	19	20	21	22	23	24	25	26	27
16	Chun et al. (2007)	JM-1 ◊◊	0.44	13.8	26	25.6	18.7	3.0	3.4	4.9	5.6	5.3	6.1	17.3	1.1
		JM-2 ◊◊	0.44	13.8	26	25.6	18.7	1.7	2.0	4.6	5.2	5.0	5.7	16.8	1.1
		WM ¤, ◊◊	0.00	31.5	31	31.5	31.5	6.6	5.2	3.4	2.7	4.0	3.1	13.1	0.7
		JM-No.11-1a	1.20	17.7	26	25.6	21.7	5.9	4.2	3.9	2.8	4.8	3.4	17.1	1.0
		JM-No.11-1b	1.20	17.7	26	25.6	21.7	5.9	4.2	3.9	2.8	4.8	3.4	17.1	1.0
17	Ishida et al. (2007)	P1 ‡‡	1.33	31.5	16	15.7	15.7	3.9	4.5	-	-	1.3	1.5	13.7	1.2
		P2 ‡‡	1.33	31.5	16	15.7	15.7	3.9	4.5	-	-	1.3	1.5	13.7	1.2
		P3 ‡‡	1.33	31.5	16	15.7	15.7	3.9	4.5	-	-	1.3	1.5	13.7	1.2
		P4 ‡‡	1.33	39.5	16	15.7	15.7	3.9	4.5	-	-	1.3	1.5	13.7	1.2
18	Tazaki et al. (2007)	E1	0.29	11.8	12	11.8	11.8	1.6	2.5	0.5	0.8	1.1	1.7	10.0	1.0
		E2 §	0.29	11.8	12	11.8	11.8	1.6	2.5	0.5	0.8	1.1	1.7	10.0	1.6
19	Lee and Yu (2009)	W0-M1	0.99	12.0	24	24.0	16.0	2.0	2.2	8.0	9.2	8.7	9.9	16.0	1.3
		W150-M1	0.99	12.0	24	12.0	14.4	2.0	2.2	2.0	2.3	2.6	3.0	16.0	1.3
		W0-M2	0.99	12.0	24	24.0	16.0	2.0	2.2	8.0	9.2	8.7	9.9	16.0	1.3
		W150-M2	0.99	12.0	24	12.0	14.4	2.0	2.2	2.0	2.3	2.6	3.0	16.0	1.3
20	Kang et al. (2010)	JD §	1.32	17.7	18	17.7	17.7	3.9	5.2	2.4	3.2	2.7	3.6	19.8	1.8
21	Kang et al. (2012)	JH-R1	0.99	10.0	15	15.0	12.5	2.3	3.1	0.6	0.8	1.2	1.6	14.4	1.3
		JH-R2	0.99	10.0	15	15.0	12.5	1.7	2.3	0.6	0.8	1.2	1.6	13.6	1.2
22	Chun and Shin (2014) ◊◊	M0.7S ‡	0.43	9.8	12	12.0	10.9	1.7	2.3	2.5	3.3	3.0	3.9	5.9	0.7
		M1.0S	1.56	9.8	12	12.0	10.9	1.7	2.3	2.5	3.3	3.0	3.9	9.8	1.1
		M1.5S §	2.60	9.8	12	12.0	10.9	1.7	2.3	2.5	3.3	3.0	3.9	15.7	1.7
		M2.0S §	3.64	9.8	12	12.0	10.9	1.7	2.3	2.5	3.3	3.0	3.9	21.6	2.4
		M2.5S §	4.68	9.8	12	12.0	10.9	1.7	2.3	2.5	3.3	3.0	3.9	27.5	3.1
		M0.7U ‡	0.33	9.8	12	12.0	10.9	1.7	2.3	2.5	3.3	3.0	3.9	5.9	0.7
		M1.0U	0.99	9.8	12	12.0	10.9	1.7	2.3	2.5	3.3	3.0	3.9	9.8	1.1
23	Dhake et al. (2015)	J4 ¤	0.00	5.9	6	5.9	5.9	3.5	7.5	0.7	1.4	0.9	2.0	5.9	1.0
		J5 ¤	0.00	5.9	6	5.9	5.9	3.5	7.5	0.7	1.4	0.9	2.0	5.9	1.5
		J9	0.29	5.9	6	5.9	5.9	3.5	7.5	0.7	1.4	0.9	2.0	5.9	1.0

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

¤ Specimens did not contain confining reinforcement parallel to the headed bars within the joint region

◊◊ Heads contained obstruction with diameter d_{obs} of $1.5d_b$ and length $t_{obs} \leq 0.6d_b$ for ≥ No.8 (D25) bars or ≤ smaller of 0.6 in. and $0.75d_b$ for < No.8 (D25) bars. Therefore, the obstruction is not considered to detract from the net bearing area of the head.

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimens had $d/\ell_{eh} > 1.5$

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	d' (in.)	d_b (in.)	$d_{b,sprt}$ (in.)	f_{cm} (psi)	f_y (ksi)	$f_{y,\,sprt}$ (ksi)	f_{yt} (ksi)	$f_{yt}A_v$ (kips)	f_{yto} (ksi)	h_b (in.)	h_c (in.)
	1	2	28	29	30	31	32	33	34	35	36	37	38
16	Chun et al. (2007)	JM-1 [◊◊]	2.4	0.875	0.875	8950	58.4	58.4	55.7	24.5	55.7	19.7	19.7
		JM-2 [◊◊]	2.4	0.875	0.875	8720	58.4	58.4	55.7	24.5	55.7	19.7	19.7
		WM [¤, ◊◊]	2.6	1.27	1.27	8180	62.5	62.5	0.0	0.0	55.7	15.7	23.6
		JM-No.11-1a	2.8	1.41	1.41	4760	66.4	66.4	72.5	87.0	72.5	19.9	20.5
		JM-No.11-1b	2.8	1.41	1.41	4760	66.4	66.4	72.5	87.0	72.5	19.9	20.5
17	Ishida et al. (2007)	P1 [‡‡]	2.0	0.875	1	3480	76.0	76.0	113.8	151.2	113.8	15.7	15.7
		P2 [‡‡]	2.0	0.875	1	3480	76.0	76.0	113.8	151.2	113.8	15.7	15.7
		P3 [‡‡]	2.0	0.875	1	3480	76.0	76.0	113.8	151.2	113.8	15.7	15.7
		P4 [‡‡]	2.0	0.875	1	3480	76.0	76.0	113.8	151.2	113.8	15.7	15.7
18	Tazaki et al. (2007)	E1	1.9	0.625	0.625	4410	55.0	55.0	53.1	15.6	53.1	11.8	11.8
		E2 [§]	1.9	0.625	0.625	4410	55.0	55.0	53.1	15.6	53.1	11.8	11.8
19	Lee and Yu (2009)	W0-M1	2.0	0.875	0.875	4450	68.6	68.6	68.0	67.3	68.0	18.0	16.0
		W150-M1	2.0	0.875	0.875	5190	68.6	68.6	68.0	67.3	68.0	18.0	16.0
		W0-M2	2.0	0.875	0.875	4450	68.6	68.6	68.0	67.3	68.0	18.0	16.0
		W150-M2	2.0	0.875	0.875	5190	68.6	68.6	68.0	67.3	68.0	18.0	16.0
20	Kang et al. (2010)	JD [§]	1.5	0.75	1	4220	69.8	59.0	83.0	109.6	83.0	21.3	17.7
21	Kang et al. (2012)	JH-R1	1.5	0.75	0.75	4360	69.5	69.5	69.5	68.8	69.5	15.9	15.0
		JH-R2	2.7	0.75	0.75	4360	69.5	69.5	69.5	68.8	69.5	15.9	15.0
22	Chun and Shin (2014) [◊◊]	M0.7S [‡]	2.5	0.75	0.875	3710	70.8	66.8	66.7	28.9	66.7	7.9	12.0
		M1.0S	2.5	0.75	0.875	3710	70.8	66.8	66.7	104.1	66.7	11.8	12.0
		M1.5S [§]	2.5	0.75	0.875	3480	70.8	66.8	66.7	173.5	66.7	17.7	12.0
		M2.0S [§]	2.5	0.75	0.875	3830	70.8	66.8	66.7	242.9	66.7	23.6	12.0
		M2.5S [§]	2.5	0.75	0.875	3830	70.8	66.8	66.7	312.3	66.7	29.5	12.0
		M0.7U [‡]	2.5	0.75	0.875	3710	70.8	66.8	62.4	20.6	62.4	7.9	12.0
		M1.0U	2.5	0.75	0.875	3710	70.8	66.8	62.4	61.8	62.4	11.8	12.0
23	Dhake et al. (2015)	J4 [¤]	1.2	0.47	0.472	4350	76.1	76.1	0.0	0.0	0.0	7.1	7.9
		J5 [¤]	1.2	0.47	0.472	4350	76.1	76.1	0.0	0.0	0.0	7.1	7.9
		J9	1.2	0.47	0.472	4350	76.1	76.1	73.6	21.7	73.6	7.1	7.9

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

¤ Specimens did not contain confining reinforcement parallel to the headed bars within the joint region

◊◊ Heads contained obstruction with diameter d_{obs} of $1.5d_b$ and length $t_{obs} \leq 0.6d_b$ for ≥ No.8 (D25) bars or ≤ smaller of 0.6 in. and $0.75d_b$ for < No.8 (D25) bars. Therefore, the obstruction is not considered to detract from the net bearing area of the head.

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimens had $d/\ell_{eh} > 1.5$

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	l_c (in.)	ℓ_{dt} [#] (in.)	ℓ_{dt}/d_b	ℓ_{dy} (in.)	ℓ_{dy}/d_b	ℓ_{eh} (in.)	ℓ_{eh}/d_b	ℓ_{ehy} (in.)	ℓ_{ehy}/d_b	ℓ_{eh}/h_c	ℓ_{eh}/ℓ_{dt}	ℓ_{eh}/ℓ_{dy}	ℓ_{eh}/ℓ_{ehy}
	1	2	39	40	41	42	43	44	45	46	47	48	49	50	51
16	Chun et al. (2007)	JM-1 [◊◊]	102.6	9.6	11.0	8.6	9.9	15.1	17.3	6.3	7.2	0.77	1.58	1.76	2.41
		JM-2 [◊◊]	102.6	11.6	13.3	10.0	11.4	15.1	17.3	7.4	8.4	0.77	1.30	1.52	2.05
		WM [¤, ◊◊]	102.6	17.3	13.6	14.9	11.7	18.9	14.9	12.8	10.1	0.80	1.09	1.27	1.48
		JM-No.11-1a	102.6	19.0	13.5	23.1	16.4	17.3	12.3	14.1	10.0	0.85	0.91	0.75	1.23
		JM-No.11-1b	102.6	19.0	13.5	23.1	16.4	17.3	12.3	14.1	10.0	0.85	0.91	0.75	1.23
17	Ishida et al. (2007)	P1 [‡‡]	51.2	15.1	17.3	19.8	22.6	11.9	13.6	11.2	12.9	0.76	0.79	0.60	1.06
		P2 [‡‡]	51.2	15.1	17.3	19.8	22.6	11.9	13.6	11.2	12.9	0.76	0.79	0.60	1.06
		P3 [‡‡]	51.2	15.1	17.3	19.8	22.6	11.9	13.6	11.2	12.9	0.76	0.79	0.60	1.06
		P4 [‡‡]	51.2	16.2	18.5	19.8	22.6	11.9	13.6	11.5	13.1	0.76	0.73	0.60	1.04
18	Tazaki et al. (2007)	E1	57.9	8.6	13.7	11.1	17.7	10.2	16.3	5.6	8.9	0.86	1.18	0.92	1.82
		E2 [§]	57.9	9.3	14.8	11.6	18.6	6.3	10.0	5.7	9.1	0.53	0.68	0.54	1.10
19	Lee and Yu (2009)	W0-M1	106.3	13.8	15.8	21.4	24.4	12.1	13.8	9.5	10.8	0.75	0.87	0.56	1.27
		W150-M1	106.3	13.3	15.2	19.5	22.3	12.1	13.8	9.1	10.5	0.75	0.91	0.62	1.32
		W0-M2	106.3	13.8	15.8	21.4	24.4	12.1	13.8	9.5	10.8	0.75	0.87	0.56	1.27
		W150-M2	106.3	13.3	15.2	19.5	22.3	12.1	13.8	9.1	10.5	0.75	0.91	0.62	1.32
20	Kang et al. (2010)	JD [§]	141.7	7.5	10.0	13.9	18.5	11.3	15.0	5.7	7.6	0.64	1.50	0.81	1.98
21	Kang et al. (2012)	JH-R1	81.0	12.0	16.0	14.8	19.7	11.3	15.0	8.7	11.5	0.75	0.94	0.76	1.30
		JH-R2	81.0	12.7	17.0	17.1	22.8	11.3	15.0	9.3	12.4	0.75	0.88	0.66	1.21
22	Chun and Shin (2014) [◊◊]	M0.7S [‡]	140.6	8.9	11.8	14.9	19.9	9.0	12.0	7.5	10.0	0.75	1.01	0.60	1.20
		M1.0S	140.6	8.7	11.6	14.9	19.9	9.0	12.0	7.5	10.0	0.75	1.04	0.60	1.20
		M1.5S [§]	140.6	8.8	11.8	15.3	20.4	9.0	12.0	7.6	10.1	0.75	1.02	0.59	1.18
		M2.0S [§]	140.6	8.6	11.5	14.7	19.7	9.0	12.0	7.4	9.9	0.75	1.04	0.61	1.21
		M2.5S [§]	140.6	8.6	11.5	14.7	19.7	9.0	12.0	7.4	9.9	0.75	1.04	0.61	1.21
		M0.7U [‡]	140.6	10.8	14.4	14.9	19.9	9.0	12.0	7.8	10.4	0.75	0.83	0.60	1.15
		M1.0U	140.6	8.7	11.6	14.9	19.9	9.0	12.0	7.5	10.0	0.75	1.04	0.60	1.20
23	Dhake et al. (2015)	J4 [¤]	35.4	5.2	10.9	9.9	20.9	5.9	12.5	3.7	7.8	0.75	1.15	0.60	1.61
		J5 [¤]	35.4	5.2	10.9	9.9	20.9	4.0	8.5	3.7	7.8	0.51	0.78	0.41	1.09
		J9	35.4	4.0	8.4	9.9	20.9	5.9	12.5	3.3	7.0	0.75	1.49	0.60	1.79

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¤ Specimens did not contain confining reinforcement parallel to the headed bars within the joint region

◊◊ Heads contained obstruction with diameter d_{obs} of $1.5d_b$ and length $t_{obs} \leq 0.6d_b$ for ≥ No.8 (D25) bars or ≤ smaller of 0.6 in. and $0.75d_b$ for < No.8 (D25) bars. Therefore, the obstruction is not considered to detract from the net bearing area of the head.

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§ Specimens had $d/\ell_{eh} > 1.5$

\# ℓ_{dt} based on Eq. (5.2) in Ghimire et al. (2018)

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	M_n (kip.in.)	M_{peak} (kip.in.)	M_{peak} / M_n	N	N_{arg} (kips)	N_{cbg} (kips)	N_{sb} (kips)	N_{sbg} (kips)	N_{splt} ◊	N_{total}	N_{tr}
	1	2	52	53	54	55	56	57	58	59	60	61	62
16	Chun et al. (2007)	JM-1 ◊◊	2358	2965	1.26	2	30.6	73.1	88.3	-	9	4	2
		JM-2 ◊◊	4396	5036	1.15	2	30.6	74.5	81.9	86.2	9	4	2
		WM ¤, ◊◊	4859	5558	1.14	0	-	92.8	98.6	-	5	0	0
		JM-No.11-1a	4637	4894	1.06	6	101.5	56.1	124.6	-	6	6	4
		JM-No.11-1b	4637	4779	1.03	6	101.5	56.1	124.6	-	6	6	4
17	Ishida et al. (2007)	P1 ‡‡	3842	3950	1.03	8	201.0	32.0	-	-	8	12	8
		P2 ‡‡	3842	4001	1.04	8	201.0	32.0	-	-	8	12	8
		P3 ‡‡	3842	4399	1.14	8	201.0	32.0	-	-	8	12	8
		P4 ‡‡	4919	4681	0.95	8	201.0	32.0	-	-	8	12	8
18	Tazaki et al. (2007)	E1	901	1084	1.20	4	25.0	19.1	21.3	25.4	4	6	6
		E2 §	901	951	1.06	2	15.1	15.8	21.3	25.4	2	6	4
19	Lee and Yu (2009)	W0-M1	2336	2769	1.19	3	97.2	47.3	-	-	3	9	3
		W150-M1	2378	2805	1.18	3	59.8	45.1	48.9	-	3	9	3
		W0-M2	2378	2805	1.18	3	59.8	47.3	-	-	3	9	3
		W150-M2	2378	2909	1.22	3	59.8	45.1	48.9	-	3	9	3
20	Kang et al. (2010)	JD §	2313	2697	1.17	4	45.7	29.1	34.3	-	6	12	2
21	Kang et al. (2012)	JH-R1	1566	1885	1.20	3	68.8	24.1	25.1	-	5	9	3
		JH-R2	1458	1708	1.17	3	68.8	25.4	25.1	29.7	5	9	3
22	Chun and Shin (2014) ◊◊	M0.7S ‡	540	564	1.04	3	68.0	17.0	43.0	-	5	3	6
		M1.0S	970	1068	1.10	5	68.0	17.0	43.0	-	5	8	6
		M1.5S §	1689	1872	1.11	5	68.0	16.4	41.7	-	5	13	6
		M2.0S §	2448	2580	1.05	5	68.0	17.2	43.7	-	5	18	6
		M2.5S §	3183	3264	1.03	5	68.0	17.2	43.7	-	5	23	6
		M0.7U ‡	540	576	1.07	3	41.2	17.0	43.0	-	5	3	6
		M1.0U	970	1140	1.18	6	41.2	17.0	43.0	-	5	9	6
23	Dhake et al. (2015)	J4 ¤	144	180	1.25	0	-	7.0	10.4	-	2	0	0
		J5 ¤	144	157	1.09	0	-	5.9	10.4	-	2	0	0
		J9	144	203	1.41	4	14.4	7.0	10.4	-	2	6	4

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◊◊ Heads contained obstruction with diameter d_{obs} of 1.5d_b and length $t_{obs} \leq 0.6d_b$ for ≥ No.8 (D25) bars or ≤ smaller of 0.6 in. and 0.75d_b for < No.8 (D25) bars. Therefore, the obstruction is not considered to detract from the net bearing area of the head.

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§ Specimens had $d/\ell_{eh} > 1.5$

◊ N_{splt} is used as N when calculating ℓ_{dy} [Eq. (4.6) in Ghimire et al. (2018)]

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		**Specimen**	N_{tro}	n	nT' (kips)	$n_{l,sprt}$	n_{sprt}	$P/A_gf'_c$	s_h/d_b	s'_{tr} (in.)	s_{tr} (in.)	s'_{tro} (in.)	s_{tro} (in.)	s_v/d_b	T_{anc} (kips)
	1	2	63	64	65	66	67	68	69	70	71	72	73	74	75
16	Chun et al. (2007)	JM-1 ◊◊	3	4	178.4	4	16	0.05	3.4	4.5	5.9	5.4	5.9	-	18.3
		JM-2 ◊◊	3	8	325.4	4	16	0.05	3.4	2.8	5.9	5.4	5.9	2.0	9.3
		WM ¤, ◊◊	0	5	453.9	0	8	0.05	5.2	-	-	5.9	11.8	-	18.6
		JM-No.11-1a	3	3	328.0	4	10	0.00	4.2	2.4	4.7	6.0	4.7	-	33.8
		JM-No.11-1b	3	3	320.3	4	10	0.00	4.2	2.4	4.7	6.0	4.7	-	33.8
17	Ishida et al. (2007)	P1 ‡‡	8	7	328.2	8	12	0.12	4.5	2.0	3.9	2.0	3.9	-	28.7
		P2 ‡‡	8	7	332.4	8	12	0.12	4.5	2.0	3.9	2.0	3.9	-	28.7
		P3 ‡‡	8	7	365.5	8	12	0.12	4.5	2.0	3.9	2.0	3.9	-	28.7
		P4 ‡‡	8	9	390.5	8	12	0.12	4.5	2.0	3.9	2.0	3.9	-	22.3
18	Tazaki et al. (2007)	E1	4	6	122.3	4	16	0.08	4.0	0.9	2.0	1.4	2.0	2.5	4.2
		E2 §	2	6	107.3	4	16	0.08	4.0	0.9	2.0	1.4	2.0	2.5	2.6
19	Lee and Yu (2009)	W0-M1	10	4	195.2	12	12	0.10	2.2	3.0	4.0	1.5	4.0	-	24.3
		W150-M1	5	4	194.2	12	12	0.10	2.2	3.0	4.0	1.5	5.0	-	15.0
		W0-M2	5	4	194.2	12	12	0.10	2.2	3.0	4.0	1.5	6.0	-	15.0
		W150-M2	5	4	201.4	12	12	0.10	2.2	3.0	4.0	1.5	7.0	-	15.0
20	Kang et al. (2010)	JD §	3	4	143.7	8	12	0.00	5.2	1.2	4.7	1.5	5.9	-	11.4
21	Kang et al. (2012)	JH-R1	6	4	147.1	8	8	0.00	3.1	2.2	3.5	1.3	3.5	-	17.2
		JH-R2	6	4	143.2	8	8	0.00	3.1	2.2	3.5	1.3	3.5	2.3	14.9
22	Chun and Shin (2014) ◊◊	M0.7S ‡	0	4	130.1	6	8	0.00	2.3	1.1	3.0	4.9	6.0	-	17.0
		M1.0S	0	4	137.2	6	8	0.00	2.3	1.1	3.0	4.9	6.0	-	17.0
		M1.5S §	0	4	138.1	6	8	0.00	2.3	1.1	3.0	4.9	6.0	-	17.0
		M2.0S §	0	4	131.3	6	8	0.00	2.3	1.1	3.0	4.9	6.0	-	17.0
		M2.5S §	0	4	127.8	6	8	0.00	2.3	1.1	3.0	4.9	6.0	-	17.0
		M0.7U ‡	0	4	132.9	6	8	0.00	2.3	1.1	3.0	4.9	6.0	-	10.3
		M1.0U	0	4	146.4	6	8	0.00	2.3	1.1	3.0	4.9	6.0	-	10.3
23	Dhake et al. (2015)	J4 ¤	0	2	33.3	0	4	0.20	7.5	-	-	3.1	3.9	-	3.5
		J5 ¤	0	2	29.1	0	4	0.20	7.5	-	-	3.1	3.9	-	3.0
		J9	0	2	37.7	4	4	0.20	7.5	0.4	2.6	3.1	3.9	-	7.2

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

¤ Specimens did not contain confining reinforcement parallel to the headed bars within the joint region

◊◊ Heads contained obstruction with diameter d_{obs} of $1.5d_b$ and length $t_{obs} \leq 0.6d_b$ for ≥ No.8 (D25) bars or ≤ smaller of 0.6 in. and $0.75d_b$ for < No.8 (D25) bars. Therefore, the obstruction is not considered to detract from the net bearing area of the head.

‡ Analyzed as doubly-reinforced section to calculate M_n; all other specimens are analyzed as singly-reinforced

‡‡ Specimens contained transverse beams on one or both sides of the test beam. These transverse beams, however, did not meet the dimensional requirements of Section 15.2.8 of ACI 318-19 and Section 4.3 of ACI 352R-02 to be considered effective in increasing the joint shear strength.

§ Specimens had $d/\ell_{eh} > 1.5$

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	T_h (kips)	T' (kips)	T'_{mod} (kips)	T'/T_{anc}	T'/T_h	T'_{mod}/T_h	t_{obs}/d_b	V_n (kips)	$V_{n,ACI352}$ (kips)	V_p (kips)
	1	2	76	77	78	79	80	81	82	83	84	85
16	Chun et al. (2007)	JM-1 ◊◊	35.1	44.6	38.6	2.44	1.27	1.10	0.5	572	418	149
		JM-2 ◊◊	35.1	40.7	36.2	4.37	1.16	1.03	0.5	564	413	276
		WM ¤, ◊◊	79.4	90.8	86.2	4.89	1.14	1.09	0.6	807	807	400
		JM-No.11-1a	103.6	109.3	106.4	3.23	1.06	1.03	0.7	434	367	280
		JM-No.11-1b	103.6	106.8	103.8	3.16	1.03	1.00	0.7	434	367	274
17	Ishida et al. (2007)	P1 ‡‡	45.6	46.9	46.6	1.63	1.03	1.02	-	176	176	251
		P2 ‡‡	45.6	47.5	47.2	1.65	1.04	1.03	-	176	176	254
		P3 ‡‡	45.6	52.2	51.9	1.82	1.14	1.14	-	176	176	280
		P4 ‡‡	45.6	43.4	43.2	1.94	0.95	0.95	-	176	176	299
18	Tazaki et al. (2007)	E1	16.9	20.4	18.7	4.90	1.20	1.10	0.0	111	111	104
		E2 §	16.9	17.9	17.7	6.78	1.06	1.04	0.0	111	111	91
19	Lee and Yu (2009)	W0-M1	41.2	48.8	47.4	2.01	1.19	1.15	2.1	307	205	169
		W150-M1	41.2	48.5	47.0	3.25	1.18	1.14	2.1	166	199	168
		W0-M2	41.2	48.5	47.2	3.25	1.18	1.15	2.1	307	205	168
		W150-M2	41.2	50.4	48.8	3.37	1.22	1.18	2.1	166	199	174
20	Kang et al. (2010)	JD §	30.8	35.9	32.3	3.15	1.17	1.05	0.0	245	245	125
21	Kang et al. (2012)	JH-R1	30.6	36.8	35.7	2.14	1.20	1.17	0.0	177	148	124
		JH-R2	30.6	35.8	35.0	2.41	1.17	1.15	0.0	177	148	122
22	Chun and Shin (2014) ◊◊	M0.7S ‡	31.2	32.5	31.8	1.91	1.04	1.02	0.7	105	96	126
		M1.0S	31.2	34.3	33.5	2.02	1.10	1.08	0.7	105	96	130
		M1.5S §	31.2	34.5	33.8	2.03	1.11	1.09	0.7	102	93	125
		M2.0S §	31.2	32.8	32.0	1.93	1.05	1.03	0.7	107	97	113
		M2.5S §	31.2	31.9	31.1	1.88	1.03	1.00	0.7	107	97	105
		M0.7U ‡	31.2	33.2	32.7	3.23	1.07	1.05	0.7	105	96	129
		M1.0U	31.2	36.6	35.8	3.56	1.18	1.15	0.7	105	96	138
23	Dhake et al. (2015)	J4 ¤	13.3	16.6	15.6	4.75	1.25	1.17	0.0	37	37	28
		J5 ¤	13.3	14.6	14.4	4.92	1.09	1.08	0.0	37	37	25
		J9	13.3	18.8	17.6	2.61	1.41	1.32	0.0	37	37	32

* Columns arranged in alphabetical order of notation; notation described in Appendix A; values given in SI are converted to in.-lb (1 in. = 25.4 mm; 1 psi = 1/145 MPa; and 1 kip = 4.4484 kN)

¤ Specimens did not contain confining reinforcement parallel to the headed bars within the joint region

◊◊ Heads contained obstruction with diameter d_{obs} of $1.5d_b$ and length $t_{obs} \leq 0.6d_b$ for ≥ No.8 (D25) bars or ≤ smaller of 0.6 in. and $0.75d_b$ for < No.8 (D25) bars. Therefore, the obstruction is not considered to detract from the net bearing area of the head.

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§ Specimens had $d/\ell_{eh} > 1.5$

Table A.1 Cont. Data for exterior and roof-level interior beam-column joint specimens tested under reversed cyclic loading *

Study		Specimen	V_p / V_n	$\delta_{0.8peak}$	δ_y	Υ_j	ψ_{cs} [##]	ψ_o
	1	2	86	87	88	89	90	91
16	Chun et al. (2007)	JM-1 [◊◊]	0.26	0.068	0.005	0.001	0.78	1.00
		JM-2 [◊◊]	0.49	0.040	0.009	0.011	0.94	1.00
		WM [¤, ◊◊]	0.50	0.084	0.013	-	0.74	1.00
		JM-No.11-1a	0.65	0.079	0.016	0.003	0.57	1.00
		JM-No.11-1b	0.63	0.065	0.018	0.006	0.57	1.00
17	Ishida et al. (2007)	P1 [‡‡]	1.43	0.015	0.012	-	0.60	1.25
		P2 [‡‡]	1.45	0.030	0.010	-	0.60	1.25
		P3 [‡‡]	1.59	0.030	0.012	-	0.60	1.25
		P4 [‡‡]	1.70	0.030	0.013	-	0.64	1.25
18	Tazaki et al. (2007)	E1	0.93	0.060	0.005	0.008	0.82	1.25
		E2 [§]	0.82	0.060	0.015	0.007	0.89	1.25
19	Lee and Yu (2009)	W0-M1	0.55	0.080	0.010	-	0.80	1.00
		W150-M1	1.01	0.080	0.010	0.001	0.80	1.00
		W0-M2	0.55	0.080	0.013	-	0.80	1.00
		W150-M2	1.05	0.080	0.080	-	0.80	1.00
20	Kang et al. (2010)	JD [§]	0.51	0.036	0.006	0.001	0.53	1.00
21	Kang et al. (2012)	JH-R1	0.70	0.050	0.019	0.008	0.69	1.25
		JH-R2	0.69	0.050	0.015	0.010	0.73	1.25
22	Chun and Shin (2014) [◊◊]	M0.7S [‡]	1.20	0.100	0.030	0.003	0.60	1.00
		M1.0S	1.23	0.090	0.020	0.005	0.59	1.00
		M1.5S [§]	1.22	0.060	0.020	0.017	0.59	1.00
		M2.0S [§]	1.06	0.050	0.020	-	0.59	1.00
		M2.5S [§]	0.98	0.035	0.020	-	0.59	1.00
		M0.7U [‡]	1.22	0.100	0.030	0.002	0.73	1.00
		M1.0U	1.31	0.100	0.020	-	0.59	1.00
23	Dhake et al. (2015)	J4 [¤]	0.77	0.040	0.012	-	0.54	1.25
		J5 [¤]	0.67	0.038	0.013	-	0.54	1.25
		J9	0.87	0.050	0.009	-	0.42	1.25

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§ Specimens had $d/\ell_{eh} > 1.5$

ψ_{cs} is based on Table 5.1 in Ghimire et al. (2018)